MAY 3 1926

Vol. IX, No. 2 PSYCHOLOGICAL REVIEW PUBLICATIONS APRIL, 1926

Journal of Experimental Psychology

EDITED BY

MADISON BENTLEY, UNIVERSITY OF ILLINOIS

HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)

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PUBLISHED BI-MONTHLY BY

PSYCHOLOGICAL REVIEW COMPANY

PRINCE AND LEMON STREETS, LANCASTER, PA., AND

PRINCETON, N. J.

Entered as second-class matter, July 1, 1920, at the post-office at Lancaster, Pa.

Psychological Review Publications

EDITED BY

HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
JOHN B. WATSON, 244 MADISON AVE., NEW YORK (*Review*)
SHEPHERD I. FRANZ, UNIV. OF CALIF., SO. BR. (*Monographs*)
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Psychological Monographs: $6.00 per volume (Foreign, $6.30).
Current Issues: prices vary according to size.

Subscriptions, orders, and business communications may be sent direct to the

PRINCETON, N. J. OFFICE

PSYCHOLOGICAL REVIEW COMPANY

FOREIGN AGENTS: G. E. STECHERT & CO., London (2 Star Yard, Cary St., W.C.), Paris (16, rue de Condé)

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Journal of
Experimental Psychology

VOL. IX., No. 2 APRIL, 1926

THE FACTOR OF SPEED IN INTELLIGENCE[1]

BY HELEN PEAK AND EDWIN G. BORING

Harvard University

THE PROBLEM

Except by way of speculation and opinion,[2] the systematic psychology of intelligence remains almost untouched. Observationally one can say little more about intelligence than that it is what the intelligence tests test. So defined we can then go much further and state a variety of psycho-social capacities that depend in a measurable degree upon intelligence as the tests test it, but all this work has brought us little farther toward an understanding of the nature of intelligence, its meaning in psychological and physiological terms, and hence its position in the body of psycho-physiological fact. The present paper seeks to make from this point of view an initial attack upon the problem of speed in intelligence (as the tests test it). We wish to point out, however, that the experiments presented, although illustrative of certain points and indicative of others, are not sufficiently extended to determine conclusively the relation of intelligence to speed. We think that they indicate what the ultimate conclusion is likely to be, and that they point the way to a program of investigation.

Among intelligence tests we have the speed tests and the

[1] From the Harvard Psychological Laboratory. The junior author has conducted the experiment, tabulated the data, and made most of the computations; the senior author has collaborated with her in the interpretation of the results.

[2] For example, see the Symposium on Intelligence and its Measurement by fourteen authors, *J. Educ. Psychol.*, 1921, 12, 123–147, 195–216, 271–275.

all-or-none tests.[3] Because psychologists have sought to find and to measure an intelligence that is independent of the speed of reaction of the subject, the all-or-none tests are often taken to be the ideal. The line between the two types of test can not, however, be sharply drawn. "Are 'allow' and 'permit' the same or opposite?" is a speed test for an English-speaking adult; whereas "Does turpentine come from petroleum, ore, hides, or trees?" is an all-or-none test for the same person, for he either knows or does not know. Moreover, the test that depends upon the meanings of 'allow' and 'permit' becomes an all-or-none test for a child of eight or for a German adult; and in general speed tests for adults are likely to become all-or-none tests for children, and all-or-none tests for children are likely to be speed tests for adults.[4]

From these remarks it appears that the all-or-none test is not a test of human performance that does not involve speed, but is simply a test that does not take account of speed. Such tests may be extremely valuable, especially as tests of information, and the neglect of speed is justified where the purpose is to test the availability of information in situations where time is of no importance. The all-or-none tests tend, however, to become tests of accomplished learning, and thus to be educational tests,[5] in a broad manner of speaking, rather than intelligence tests, except in so far as intelligence is held to imply educability, and education, with a normal exposure

[3] 'Rate' tests and 'power' tests are the more usual phrases; *cf.* W. S. Monroe, Introduction to Theory of Educational Measurement, 1923, 63; M. R. Trabue, 'Measuring Results in Education,' 1924, 331–333, 336 *f.* Miss Margaret Kennedy of the Harvard Graduate School of Education, in an experimental study, as yet unpublished, substitutes the phrase 'all-or-none' for 'power.' The former phrase is to be much preferred, for 'power' is well established in scientific usage as rate of work, and its application to the all-or-none test is an exact reversal of its accepted meaning. *Cf.* the last section of this paper.

[4] Here we have especially in mind Miss Kennedy's investigation to which we have just referred.

[5] The difficulty of distinguishing between intelligence tests and educational tests, or between the educational and intelligent factors that enter into performance in an intelligence test, is well known. *Cf.*, *e.g.*, C. Burt, Mental and Scholastic Tests, 1921, esp. 175–183; Trabue, *op. cit.*, 318–320; R. Pintner, Intelligence Testing, 1923, 60 f., 160–163; Psychological Examining in U. S. Army, *Mem. Nat. Acad. Sci.*, 1921, 15, 764 ff., 779 ff.; *etc.* Professor W. F. Dearborn's Lowell Lectures (as yet unpublished) are also in point.

to social influences, is thus believed to measure intelligence. Even here, however, it may be pointed out that something might be gained were the all-or-none tests not to neglect time. If these tests measure learning, so does the method of right associates, and Müller and Pilzecker found that this method was greatly sensitized by adding to it a measurement of the association reaction times.[6]

The essence of the intelligent reaction seems to be the solution of a problem against time. The most obvious and the most general variable in this reaction is the time, although it is plainly not the only important variable. If the organism may not be prepared to solve the problem at all in any amount of time, then we have the all-or-none test. If, however, a subject solves an all-or-none test, then clearly the time becomes important: it is not so good a solution for him to solve it slowly as to solve it rapidly; and neglect of differences in time is thus a neglect of important differentiæ. In fact the all-or-none test may be regarded simply as the limit of the fast-or-slow test, the limit where the time required is recorded simply as finite or infinite. It is plain that the all-or-none test, measuring an essentially temporal act, nevertheless sets conditions which force it to disregard times because the times obtained are of the least precise order.

At any rate, speed is so important in the intelligent act that it has seemed to us the first factor to be studied if we are ultimately to come at an understanding of the nature of intelligence.[7]

In respect of speed there are various problems. If the speed of the intelligent act can be isolated, there arises the problem of its identification with intelligence as the tests test it. Will pure speed tests correlate as highly with psychological and social capacities as have intelligence tests? If they will not, what other factors must be considered?

[6] The *Treffer- und Zeitmethode* of G. E. Müller and A. Pilzecker, *Experimentelle Beiträge zur Lehre vom Gedächtniss*, 1900. The *Treffermethode* by itself is practically an all-or-none mental test, yet Müller and Pilzecker saw the importance of taking account of time.

[7] E. L. Thorndike proposes the analysis of ability into level, range, and speed: *J. Educ. Research*, 1925, 11, 1–11, esp. 9 f. Against his tendency to view these three as at least equally important, we set the argument of the text for the fundamental relation of speed to mental activity.

There is also, however, the problem of the locus of the speed, a problem which points more directly toward the fundamental nature of intelligence. Suppose we find that the man who does poorly in an intelligence test can do just as well as the man who did well, provided he is given more time than the other man. If there are no items of the all-or-none kind, he may, of course, if given more time, do just as well. Now the problem of intelligence, as such a test tests it, has become entirely a matter of speed; and the first thing to do, we think, is to localize the wasted time.

There are two possibilities. The loss of time by the 'less intelligent' subject may be interstitial or it may be inherent in the intelligent act. It would be interstitial if the good and the poor subject performed every required operation at equal speed, but the poor subject was less able to limit himself to the essential requirements and lost time by irrelevant activities or by self-distraction. Everyone knows how conscious effort itself may become a distraction from the task upon which the effort is directed, and it is possible that a great deal of irrelevant 'thought' accounts for the slowness of the subject who does poorly in an intelligence test. On the other hand, the loss of time may be said to be inherent in the intelligent act, if, as far as analysis can be pressed, it is found that the constituents of the act occur more slowly in the poor subject than in the good subject. It is with this problem that we are concerned in the present paper.

The first step in analysis consists in measuring the times of the separate items of an intelligence test. We must find out whether in the Army Alpha Examination, for example, there is a tendency for the poor subject to do every one of the 212 items more slowly than does the good subject. If he does in general, then it is clear that any distractions that cause him to lose time are not of the gross order that could be revealed by introspection under ordinary introspective conditions. If, however, the poor subject equals the good subject in some stretches of the test, but falls behind on account of abrupt retardations, then an appeal might readily be made to an introspective investigation.

If, item for item, the poor subject tends to be slower than the good subject, then we must push our analysis within the item. Our first interest will be in the simplest items, like those of the 'same-and-opposite' test. If the single items of this test show the same time-difference as does the examination as a whole, we can see whether we shall find the same individual differences in associative reaction times, in cognitive reaction times, in simple reaction times, in reflex times, and ultimately, if necessary, in the rates of nerve-conduction. If it be argued that we should not expect a difference in the rates of nerve conduction, then we may point out that somewhere in the series of times just listed the time-differences, apparent in the intelligence test, would disappear, and we should have localized the level of complexity at which the difference in time appears. Such a localization we think of as a first step toward the solution of the problem of the nature of intelligence.

The Experiment

We had five laboratory subjects: *A*, *B*, *C*, *D*, and *E*.[8] Two of the subjects were men, graduate students of psychology; the other three were women, advanced undergraduates, conducting experimental problems in the Harvard Psychological Laboratory. Laboratory subjects of this sort are presumably a highly selected group in respect of intelligence. Laboratory conditions, however, are ideal for precise measurement, and the consequent gain in precision may render significant the small difference in intelligence that the tests reveal in the selected group. We think that the present paper demonstrates the feasibility of studying intelligence in the laboratory with a few selected subjects, even though it would be necessary ultimately to check the conclusions formed in the laboratory by recourse to a larger and more heterogeneous group.

These subjects were all given forms 5 and 6 of the Army Alpha Examination, and forms A and B of the Higher Examination of the Otis Self-Administering Tests of Mental Ability.

[8] These letters were assigned to the subjects after the computation of the data so that the order *A*, *B*, *C*, *D*, *E* might be also the average order of intelligence and of speed; *cf.* Table VI.

Each subject took his test alone with the experimenter, one test at a sitting with an interval of a week or more between sittings. The order of the tests for all subjects was: Otis A, Alpha 5, Otis B, Alpha 6.

The subjects were given the usual instructions for the Otis Test, for every test of Examination Alpha, and for the separate items of test 1 of Alpha, except that all reference to time-limits was omitted. They were also given the following additional instructions:

> You are to answer all the items as quickly and correctly as possible. Both your speed and your accuracy will count in your score. Answer the items in order; do not skip about. If you have to give up answering an item, draw a line at the end of the item before you proceed to the next. You should continue until you have answered all the questions.

By this instruction for concurrent speed and accuracy we hoped to approximate the usual attitude of a subject in an intelligence test where time-limits are fixed, and yet to do away with the time-limits so that we could measure the speed of every subject on every item.

The experimenter sat beside the subject, a stop-watch in hand, and recorded the time in seconds for the completion of every item. When an item was omitted, the drawing of a line by the subject in the margin was the signal for the experimenter to record the time. In test 4 of Examination Alpha, the 'same-and-opposite' test, the subject's performance was too rapid for the experimenter to record the time of every item in this manner; she recorded, therefore, only the time for the completion of every fifth item, and the stated times (Table II) are for sets of five consecutive items.

Score as a Function of Time.—From these data it is possible to determine what the score for any time-limit would have been under the instruction for concurrent speed and accuracy. We have tabulated scores as a function of time for every test of Alpha and for the Otis Tests. In Table I. these results for certain times are given for both forms of Alpha. The two forms will be seen to give similar functions, and the same data for the Otis Tests are not given because they are similar to Alpha.

TABLE I

SCORES IN EXAMINATION ALPHA AS A FUNCTION OF TIME ALLOWED

Time is expressed as the ratio to the standard time-limits, *i.e.*, 1 = standard time-allowance. Scores are number of items correct (errors are not subtracted). Five subjects, *A*, *B*, *C*, *D*, and *E*. 'Unlimited time' is the total time taken by the slowest subject; for form 5 it is 3.8, and for form 6, 3.1 times the standard time.

Time: Ratio to Standard Time	Alpha: Form 5					Alpha: Form 6				
	A	*B*	*C*	*D*	*E*	*A*	*B*	*C*	*D*	*E*
$\frac{1}{8}$	45	39	35	31	22	40	40	33	21	20
$\frac{1}{4}$	76	72	60	57	44	79	72	58	52	38
$\frac{1}{2}$	137	121	109	105	69	134	124	105	94	65
$\frac{3}{4}$	171	152	141	130	99	165	154	134	131	94
1	192	170	169	162	120	194	172	166	157	117
$1\frac{1}{4}$	201	177	180	174	140	202	174	181	173	141
$1\frac{1}{2}$	205	179	184	183	160	205	177	189	183	159
$1\frac{3}{4}$	206	180	185	187	170	206	197	189	186	170
2	209	182	187	190	181	206	197	190	188	182
$2\frac{1}{2}$	210	184	187	193	195	206	197	190	190	189
3	210	184	187	194	200	206	197	190	190	193
Unlimited	210	184	187	197	203	206	197	190	190	194

In Table I. the scores are given for the two Alpha examinations as they would have stood had the subject been stopped after $\frac{1}{8}$ of the standard time allowed in this examination for each test, after $\frac{1}{4}$ the standard time, and so on as in the table up to three times the standard time. The final item for 'unlimited' time is the sum of the final scores in each test.

Only in test 2 and only with *D* and *E* in form 5 and with *E* in form 6 did a subject require more than three times the standard time to complete a test. The maximal and minimal ratios of time required to standard time, considering all subjects and both forms, is as follows:

Alpha Test	Maximal Ratio	Minimal Ratio
1	.67	.33
8	1.63	.63
5	2.48	1.00
4	2.67	.83
7	2.67	.92
6	2.67	1.33
3	2.74	1.00
2	3.80	1.40

In test 2 *E* required 3.8 times the standard time in form 5 and 3.1 times the standard time in form 6. In tests 2, 3, 5, and 6 all subjects in both forms took more than the standard time to finish the test. Out of the 80 tests given (5 subjects × 8 tests × 2 forms) there are 19 cases of a subject's finishing in less than standard time: 5 for *A*, 5 for *B*, 3 for *C*, 4 for *D*, and 2 for *E*. Only in test 1 were the standard time-limits much too long; here every subject finished in less than the standard times.[9]

It is clear from the instruction that a subject was not permitted to go back to an item after he had passed to a succeeding one. Hence a subject, once he had completed a test, was unable to benefit further in that test by taking more time. For example, *A*, the best subject, shows little improvement from $1\frac{1}{2}$ standard time to twice standard time since at $1\frac{1}{2}$ standard time he had already finished 13 of the 16 tests and could in those tests make no use of additional time. It is for this reason also that, for the very long times, the poorer subjects have overtaken or even surpassed the better subjects.

The great similarity between forms 5 and 6 enables us to limit our further discussion of these data to form 5, the results of which are plotted in Fig. 1. The figure shows that *A* remained superior to the other subjects throughout: he was both accurate and rapid. For less than the standard times the order of excellence is *A*, *B*, *C*, *D*, *E*. Every subject improved continuously, but, for this order of subjects, at increasingly slower rates. The graphs are curved and not straight lines because Alpha is arranged in general with more difficult items at the end of each test. Beyond standard time

[9] Perhaps the very best score for the purposes of differentiating these subjects would be the score based on the 'minimal' time for each test, *i.e.*, as much time allowance as is possible without causing any subject to waste time after he has finished. These scores are as follows:

Subjects	*A*	*B*	*C*	*D*	*E*
Alpha 5	194	177	162	149	114
Alpha 6	197	177	159	151	110

Comparison with Table I. shows, however, that these scores show the same relation as is already given by the shorter times.

the curvature becomes greater due to the fact that the curves are asymptotic to the maximal score that the subject will have made. The maximal score in Alpha is 212, but, since a subject may not correct an error once made, the maximum for the subject depends upon his accuracy under the instruction for concurrent accuracy and speed.

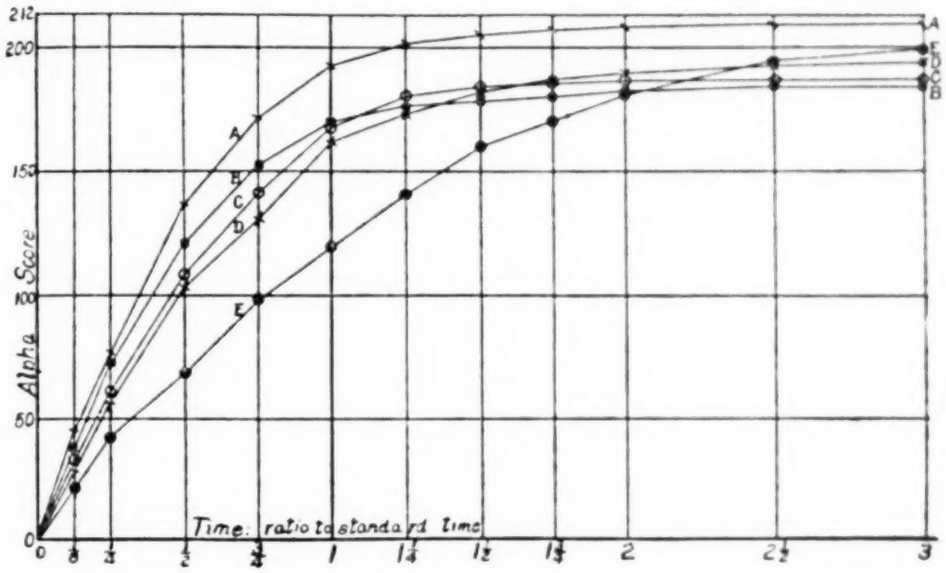

FIG. 1. Intelligence score (Alpha, Form 5) as a function of time allowed for the tests. Time expressed in fractions of standard time. Five subjects: *A*, *B*, *C*, *D*, and *E*. *Cf.* Table I.

This situation enables us to evaluate the claims of the 'slow but accurate' subject. Such a subject often complains that an intelligence test puts too much emphasis upon speed and that he might have excelled in a test of accuracy if not in a test of speed. In fact, it is probably such contentions that have popularized the all-or-none tests.

Fig. 1 shows exactly this situation. Subject *A* is superior throughout, but *C* overtakes *B* at about $1\frac{1}{8}$ standard time. *D* overtakes *B* at $1\frac{3}{8}$ and *C* at $1\frac{5}{8}$. *E* overtakes *B*, *C*, and *D* successively between 2 and $2\frac{1}{2}$. At the end *A* remains superior, but the order of *B*, *C*, *D*, and *E* is reversed from what it was up to standard time. Can we say of *B*, *C*, *D*, and *E* that the slow subject is the more accurate? No; because, psychologically regarded, accuracy can not be divorced from time. If there had been available an unlimited number of

items of equal difficulty, the graphs would have been straight lines, would have continued up from the origin with different slopes, and the individual differences would have become greater and greater as time progressed. The reversal is an artifact of this test. The relationship can be stated as follows: accuracy depends upon speed; the slower subject will be more accurate; but, if in a speed-accuracy test he ranks below a faster subject, no extension of time for both subjects will reverse the order; a reversal occurs only when the faster subject is penalized by not being given an equal additional increment of time. (The applications of this principle to life are obvious. In life time is not infinite. The slow-but-accurate person may perform a given task more accurately than his faster rival, but he accomplishes in his life-time fewer accurate acts than does his rival.)

Since speed depends upon accuracy, the only way to investigate speed is to keep accuracy a constant. We take up this matter in the next section.

Here, however, we must note that the order of intelligence of these subjects is *A*, *B*, *C*, *D*, *E*. This statement means that this is the order of the subjects in each form of Alpha and in each form of the Otis test up to the time when the faster subjects have completed some tests and are thus becoming unable to utilize time for competition. The individual differences (*cf.* Fig. 1) may seem small, but we believe they are significant, because they are repeated at the different time-limits below standard time, because they are repeated in each of the four tests, and because, as we shall see later, they show a consistent relationship to reaction time. All these relationships are set forth in Table VII.

Individual Differences in Speed.—Since differences in speed are significant only when accuracy is kept constant, we have selected from the tests those items to which all the subjects responded correctly, and have tabulated the reaction times for these items in Tables II. and III. The 265 items, which every subject answered correctly, in the two Alpha Examinations, are tabulated in Table II.; the corresponding 100 times for the Otis Tests are in Table III. Even here we must

TABLE II

TIMES (SECS.) FOR COMPLETION OF INDIVIDUAL ITEMS OF EXAMINATION ALPHA, FORMS 5 AND 6 (Referred to as 'ALPHA 5' AND 'ALPHA 6')

TABLE II

TIMES (SECS.) FOR COMPLETION OF INDIVIDUAL ITEMS OF EXAMINATION ALPHA, FORMS 5 AND 6 (Referred to as 'ALPHA 5' AND 'ALPHA 6')

The table includes only those items answered correctly by every one of the five subjects, *A*, *B*, *C*, *D*, and *E*. The numbers at the left of the section for every test are the numbers of the items in that test. The columns for the five subjects carry down to the bottom of the page.

Item	Subjects				
	A	*B*	*C*	*D*	*E*
Alpha 5: Test 1					
1	1	2	1	1	3
2	1	1	1	3	4
3	1	1	2	8	2
4	1	2	2	2	5
5	2	3	5	4	6
6	10	7	9	13	14
7	1	1	1	2	2
Alpha 6: Test 1					
1	1	1	1	2	2
2	1	1	1	4	3
3	1	1	1	2	2
4	2	1	2	1	2
5	2	2	3	4	4
6	3	2	3	5	7
7	9	7	7	10	12
8	1	1	1	1	2
Alpha 5: Test 4					
1–5	7	7	13	15	22
6–10	6	9	13	12	19
11–15	10	12	12	13	15
16–20	10	14	12	10	23
21–25	10	16	12	11	15
Alpha 6: Test 4					
1–5	9	6	9	8	16
6–10	20	16	27	21	32

Item	Subjects				
	A	*B*	*C*	*D*	*E*
Alpha 5: Test 2					
1	2	2	4	3	7
2	1	3	6	7	8
3	2	5	6	9	7
4	11	6	8	11	15
5	4	4	7	7	13
6	6	5	7	8	11
7	6	6	7	15	18
8	12	18	15	30	39
9	20	23	17	29	39
10	33	20	14	95	97
11	8	22	11	25	37
12	12	21	14	50	32
13	31	32	50	164	181
14	12	15	78	64	62
15	14	35	20	30	54
16	30	43	38	78	85
Alpha 6: Test 2					
1	1	2	4	4	6
2	3	4	4	4	7
3	3	5	6	5	6
4	3	5	7	44	15
5	3	4	5	8	9
6	3	5	6	8	13
7	4	8	5	8	14
8	11	17	17	49	55
9	8	12	7	20	16
10	13	34	28	40	59
11	55	42	17	108	243
12	28	52	37	47	71
13	27	48	44	122	50

Item	Subjects				
	A	*B*	*C*	*D*	*E*
Alpha 5: Test 3					
1	3	2	1	4	5
2	7	4	9	5	12
3	5	5	5	7	13
4	6	8	12	15	23
5	9	10	10	14	12
6	5	5	6	8	9
7	8	8	6	9	10
8	6	7	6	19	20
9	2	8	10	14	11
10	12	10	7	22	16
11	4	7	7	9	10
12	5	6	6	15	14
13	2	5	5	14	17
14	6	7	6	12	18
15	10	8	11	27	25
Alpha 6: Test 3					
1	3	2	3	2	9
2	4	8	8	15	15
3	7	7	7	10	18
4	4	4	6	8	11
5	6	5	7	13	9
6	10	7	9	13	15
7	6	7	10	9	9
8	6	4	6	7	24
9	5	6	8	9	8
10	7	4	4	6	8
11	3	4	6	21	15
12	5	5	11	8	10
13	5	4	4	6	8
14	9	10	10	10	22

Item	Subjects				
	A	*B*	*C*	*D*	*E*
Alpha 5: Test 5					
1	2	1	2	4	4
2	3	3	3	3	4
3	3	3	9	4	7
4	4	3	4	4	6
5	4	3	6	4	12
6	3	5	7	7	19
7	4	3	5	5	11
8	2	2	3	4	6
9	5	4	3	6	22
10	17	4	5	6	12
11	4	5	6	5	6
12	4	3	4	7	11
13	4	5	3	3	7
14	17	2	4	8	6
15	6	5	10	5	11
16	12	6	6	11	10
17	4	11	4	5	6
18	31	9	5	8	26
19	7	7	5	5	8
20	7	12	25	10	30

Item	Subjects				
	A	*B*	*C*	*D*	*E*
Alpha 6: Test 5					
1	3	1	2	3	4
2	4	1	3	3	7
3	5	9	4	3	7
4	3	2	2	2	4
5	4	4	3	6	6
6	3	2	3	4	9
7	3	1	3	7	7
8	4	2	3	10	7
9	10	4	5	8	7
10	4	3	4	3	6
11	6	4	6	5	12
12	4	4	3	4	12
13	8	7	8	7	17
14	4	2	6	6	8
15	5	8	9	10	6
16	4	9	3	4	5
17	4	3	12	4	10
18	4	3	12	6	13
19	7	4	12	22	5
20	6	14	6	11	5
21	12	8	9	6	18
22	7	4	5	7	18

TABLE II.—*Continued.* TIMES FOR COMPLETION OF INDIVIDUAL ITEMS OF EXAMINATION ALPHA. See legend to Table II.

Item	Subjects				
	A	*B*	*C*	*D*	*E*
	Alpha 5: Test 6				
1	1	14	3	4	9
2	4	6	4	4	5
3	3	3	7	5	6
4	4	5	4	5	14
5	6	7	13	12	20
6	5	3	8	5	9
7	7	7	7	10	13
8	14	13	7	28	16
9	13	4	8	5	8
10	20	58	44	20	17
11	43	19	29	13	12
12	10	81	11	59	38
	Alpha 6: Test 6				
1	3	2	2	2	4
2	3	5	4	4	6
3	2	2	4	5	5
4	6	2	6	5	10
5	6	2	5	6	10
6	6	7	6	9	9
7	12	13	10	11	14
8	19	16	27	22	26
9	24	9	6	16	11
10	13	7	22	24	22
11	23	15	21	13	13
12	23	12	21	8	14
13	8	11	12	12	15
14	21	21	20	9	12
15	27	11	74	20	35

Item	Subjects				
	A	*B*	*C*	*D*	*E*
	Alpha 5: Test 7				
1	2	1	3	4	7
2	3	2	2	6	4
3	2	3	3	4	7
4	6	5	3	4	6
5	2	4	6	4	5
6	3	3	3	5	9
7	1	2	3	6	13
8	5	2	3	6	13
9	3	2	3	5	6
10	6	9	6	3	18
11	6	2	5	4	7
12	7	5	3	4	9
13	5	3	4	7	8
14	5	5	3	3	10
15	5	4	5	3	6
16	2	3	4	4	14
17	5	4	6	7	14
18	3	3	3	6	7
19	2	2	5	3	14
20	3	4	5	12	11
21	8	7	6	11	21
22	5	4	6	4	7
23	7	3	3	20	10
24	5	3	3	2	9
25	16	5	5	18	6
26	4	5	3	3	8
27	3	2	6	21	17
28	6	4	4	6	2
29	4	3	4	3	29
30	4	4	5	5	10
31	7	6	5	7	20
32	14	7	6	7	26
33	6	6	6	9	15
34	6	3	6	14	8

Item	Subjects				
	A	*B*	*C*	*D*	*E*
	Alpha 6: Test 7				
1	2	1	2	2	3
2	8	3	12	6	7
3	4	4	4	5	3
4	2	1	6	10	10
5	3	1	6	3	10
6	3	2	4	3	9
7	3	3	3	4	6
8	3	2	5	3	15
9	3	2	4	3	6
10	3	4	3	7	7
11	3	3	3	2	7
12	7	3	2	4	6
13	8	3	7	6	8
14	7	3	2	6	6
15	4	5	4	9	11
16	6	10	7	5	12
17	5	4	3	3	5
18	3	2	2	7	5
19	3	6	3	5	7
20	5	5	3	4	10
21	5	2	3	4	6
22	2	3	5	3	16
23	5	16	4	14	10
24	7	4	3	11	12
25	4	2	3	6	6
26	4	2	4	3	7
27	2	3	7	3	7
28	2	5	4	7	9
29	4	2	4	5	6
30	3	3	3	5	13
31	6	6	7	6	13
32	10	4	4	18	10
33	3	5	4	7	13

Item	Subjects				
	A	*B*	*C*	*D*	*E*
	Alpha 5: Test 8				
1	2	1	1	3	10
2	2	4	3	6	6
3	3	4	4	5	7
4	3	3	5	4	9
5	4	3	3	5	13
6	2	4	5	8	5
7	5	3	8	4	4
8	12	6	4	8	8
9	3	4	8	13	12
10	1	3	3	3	4
11	5	2	3	1	5
12	5	2	5	3	4
13	4	2	4	3	4
14	4	3	3	4	8
15	2	3	3	4	15
16	4	2	3	4	2
17	3	2	6	3	6
18	2	3	6	4	8
19	6	6	6	3	9
20	2	4	4	5	5
21	3	5	5	6	4
22	2	5	6	5	8
23	3	6	8	7	9
24	7	6	6	4	8
25	9	5	4	5	4
26	3	2	4	3	6
27	2	2	3	6	7

Item	Subjects				
	A	*B*	*C*	*D*	*E*
	Alpha 6: Test 8				
1	1	2	3	3	3
2	3	4	3	7	8
3	2	3	4	3	7
4	2	6	4	3	10
5	4	2	3	4	10
6	2	3	6	4	3
7	2	2	2	2	4
8	1	5	2	4	5
9	2	3	2	4	6
10	2	2	10	2	12
11	2	5	10	4	10
12	2	2	4	4	6
13	5	3	3	5	4
14	4	3	5	3	6
15	2	3	4	7	4
16	3	4	5	3	4
17	5	3	3	3	4
18	2	2	2	3	4
19	2	3	3	3	4
20	2	3	3	5	8
21	4	2	3	4	6
22	4	3	5	4	6

TABLE III

TIMES (SECS.) FOR COMPLETION OF INDIVIDUAL ITEMS IN OTIS TEST, FORMS *A* AND *B*

The table includes only those items answered correctly by every one of the five subjects. *A*, *B*, *C*, *D*, and *E* as in Table II for similar

31	7	6	5	7	20	31	6	6	7	6	13
32	14	7	6	7	26	32	10	4	4	18	10
33	6	6	6	9	15	33	3	5	4	7	13
34	6	3	6	14	8						

TABLE III

TIMES (SECS.) FOR COMPLETION OF INDIVIDUAL ITEMS IN OTIS TEST, FORMS *A* AND *B*

The table includes only those items answered correctly by every one of the five subjects, *A*, *B*, *C*, *D*, and *E*. *Cf.* Table II for similar times with Examination Alpha and the same subjects.

Otis Test: Form *A*

Item	Subjects					Item	Subjects				
	A	*B*	*C*	*D*	*E*		*A*	*B*	*C*	*D*	*E*
1	8	4	5	7	13	31	5	6	6	12	14
2	13	18	11	17	36	32	5	6	7	13	11
3	5	11	7	9	13	33	12	18	16	15	23
4	10	24	8	14	12	34	12	20	18	37	72
5	13	5	23	30	24	35	13	8	13	14	20
6	2	3	4	12	11	36	18	23	32	400	31
7	6	5	7	12	10	37	61	34	15	79	106
8	9	11	24	30	22	38	12	5	11	17	10
9	11	19	10	12	28	39	44	39	40	28	48
10	13	6	9	14	10	40	11	15	39	25	20
11	17	6	7	14	22	41	15	14	32	37	33
12	5	5	9	17	13	42	66	36	46	73	57
13	18	14	14	12	32	43	33	10	19	22	29
14	18	35	26	30	46	44	13	11	5	18	18
15	13	12	11	15	13	45	14	8	9	13	14
16	8	10	13	20	18						
17	5	2	6	6	13						
18	7	11	6	10	13						
19	5	4	10	49	43						
20	8	17	18	20	22						
21	7	10	9	39	28						
22	17	8	13	17	16						
23	15	25	16	15	17						
24	13	22	21	22	31						
25	8	3	5	10	21						
26	22	21	30	41	34						
27	6	12	7	11	18						
28	34	26	40	32	21						
29	21	31	19	39	58						
30	19	17	8	15	18						

Otis Test: Form *B*

Item	Subjects					Item	Subjects				
	A	*B*	*C*	*D*	*E*		*A*	*B*	*C*	*D*	*E*
1	2	5	4	4	9	31	8	7	11	14	17
2	6	7	9	9	16	32	23	14	33	47	31
3	9	11	9	12	23	33	5	7	6	11	7
4	8	16	22	22	47	34	6	11	11	9	11
5	13	17	20	15	22	35	15	9	14	7	15
6	6	8	5	10	9	36	4	4	7	5	17
7	8	21	17	23	4	37	6	11	19	14	12
8	4	5	5	7	9	38	22	12	15	54	30
9	12	16	23	47	6	39	10	7	18	15	5
10	20	17	13	14	13	40	25	21	30	16	64
11	6	12	21	19	10	41	14	13	13	12	23
12	11	9	8	11	12	42	8	15	10	19	16
13	6	8	5	25	54	43	31	14	48	37	51
14	5	8	6	9	12	44	15	13	16	13	21
15	6	5	11	8	17	45	11	24	11	17	18
16	19	19	21	15	17	46	11	14	77	40	40
17	5	5	9	19	12	47	24	34	14	33	45
18	24	23	18	26	35	48	9	10	9	9	13
19	11	4	7	12	10	49	12	34	17	24	19
20	8	10	4	22	21	50	62	76	2	64	76
21	28	26	23	19	26	51	15	20	12	98	94
22	2	6	5	7	8	52	18	11	13	16	17
23	15	11	15	20	26	53	13	8	12	26	21
24	11	7	10	31	28	54	20	17	13	15	26
25	9	18	15	11	21	55	61	26	34	39	50
26	8	6	5	6	23						
27	25	27	24	33	36						
28	9	15	15	15	27						
29	44	54	16	36	79						
30	9	8	13	12	25						

realize that accuracy is not perfectly constant, since the subjective assurance of the subjects must have varied in different items; nevertheless the bare behavioral test of correctness of response does have some meaning. It is reasonable to hope that variability in the time taken to achieve subjective assurance cancels out for a single subject, whereas any constant individual difference in the degree of assurance required before passing on to a subsequent item becomes simply a factor of individual difference in speed to be analyzed out later, either by an appeal to introspection or by an investigation of simpler reaction times (*vide supra*).

Of course we are dealing here, even though within the single item, with processes that still are, when psychologically considered, very complex. Not only may the time vary by reason of the fact that the subject now pauses for verification of his response or to allow subjective assurance to accrue in some other way, and then again passes more immediately to the succeeding item; but also the entire process may be different for different subjects with the same item (*cf.* especially Alpha, test 2, arithmetical problems). We should not, therefore, expect that in every line of Tables II. and III. the rank order of subjects would be *A*, *B*, *C*, *D*, *E*. Nevertheless we think that even mere inspection of these tables will convince the reader that we are here dealing with significant individual differences in the rate of the intelligent reaction, where *A* or *B* is the fastest, *E* is the slowest, and the order is *A* and *B*, *C*, *D*, *E*.

Since inspection is dangerous, however, we may resort to statistics. We have tabulated for both Alpha and the Otis Test the relative ranking of every pair of subjects. This table takes the following form:

	B is faster than	*B* is equal to	*B* is slower than
A.....	121	41	103
C.....	142	53	70
D.....	191	31	43
E.....	244	4	17

This table must be read: "*B* is faster than *A*, in the 265 items of Alpha, 121 times;" "*B* is equal to *A* 41 times;" "*B* is faster than *C* 142 times;" *etc.* It will be noted that the frequencies of the table resemble in form the frequencies of the psychometric functions for a differential limen, and that the foregoing table leaves no doubt of the existence of a superiority of B over A in speed of reaction in Examination Alpha, although the difference between A and B in Alpha is the least significant of any individual difference with which we have to deal. Similarly we can show that C occupies a mid-position in Alpha:

	C is faster than	*C* is equal to	*C* is slower than
A	83	54	128
B	70	53	142
D	156	30	79
E	225	13	27

Unfortunately limits of space prevent us from presenting the complete table. It can easily be constructed from Tables II. and III., and it shows that the rank order is *B*, *A*, *C*, *D*, *E* for Alpha and *A*, *B*, *C*, *D*, *E* for the Otis Tests. The disparity of frequency becomes greater the more remote the subjects are in these series, as anyone accustomed to deal with psychometric functions will understand.

We can also resort to the more usual statistical procedure for the demonstration of the significance of differences. The times for each subject can be averaged, their variability determined, and the difference between averages considered in relation to their variabilities. The direct averaging of Tables II. and III., however, weights the different items unequally since some items require a longer time than others. While direct averages would be meaningful, this procedure would not give us the mean variations that we desire, since, until we press analysis further, our interest must still center in the item as a whole and we can not allow the variation of one large item to offset the contrary variation of several small items. Accordingly we have re-expressed the times of Tables II. and

III. by writing for every item 1,000 times the decimal fraction that the time is of the total time spent by the five subjects on the item in question. These values we have called the 'weighted times'; they weight every item equally and are proportional to the ratio of a particular subject's time for a given item to the average time for that item.

We can not afford space for these tables. In Table IV., however, we give the averages of these weighted times for each subject and the mean variations of these averages. The two forms of Examination Alpha are treated together, as are also the two forms of the Otis Test. It will be seen that the rank order of the subjects is the same as the order stated above: *B*, *A*, *C*, *D*, *E* for Alpha, and *A*, *B*, *C*, *D*, *E* for the Otis Tests.

TABLE IV

AVERAGE WEIGHTED TIMES AND THEIR MEAN VARIATIONS FOR SUBJECTS *A*, *B*, *C*, *D*, AND *E* IN EXAMINATION ALPHA, FORMS 5 AND 6, AND IN THE OTIS TEST, FORMS *A* AND *B*

To render the m.v.'s comparable for a comparison of subjects, the times in Tables II. and III. were written as 1000 × the ratio of the time of one subject to the total time of the five subjects in any item. The averages and m.v.'s of the table are averages and m.v.'s of these weighted times.

Subjects	Alpha: Forms 5 and 6		Otis: Forms *A* and *B*	
	Average Weighted Time	M.v.	Average Weighted Time	M.v.
A	155.45	51.70	154.40	47.76
B	145.94	44.12	158.30	51.62
C	173.53	48.30	170.62	46.12
D	217.34	62.20	241.55	62.95
E	307.90	68.86	275.18	65.87

Table V. shows the significance of the individual differences of Table IV. The probable errors of the means have been found, the differences between every pair of averages, and the probable errors of these differences. The table gives the ratio of every difference to its probable error.

It is not possible to say dogmatically whether or not these differences are significant. Significance is relative and not absolute. Every difference must be thought of as having

TABLE V

SIGNIFICANCE OF INDIVIDUAL DIFFERENCES

The figures of the table are ratios of the difference to its probable error for the average weighted times for every pair of subjects. Examination Alpha is treated in the upper right half of the table, and the Otis Test in the lower left half. All the ratios are computed directly from Table IV.

	SUBJECTS					
	A	*B*	*C*	*D*	*E*	
A		2.70‡	4.93§	14.77	34.18	
B	0.66*		8.16	17.93	38.19	
C	2.89‡	2.11†		10.73	30.88	
D	13.06	12.11	10.76		18.82	
E	17.60	16.55	15.42	4.37§		
SUBJECTS	OTIS TEST					ALPHA

Probabilities 'that the differences are not due to chance' are as follows:
* Only 0.34.
† 0.85.
‡ Between 0.90 and 0.99.
§ Between 0.99 and unity.
In all other cases they are unity (with four-place tables).

some significance, and significance increases as this ratio of the difference to its probable error increases. Sometimes we are told that a difference is significant when this ratio is as great as 3; sometimes that it should be 5 or 6. It is between 5 and 6 that four-place probability tables give the probability 'that the difference is not due to chance' as 'certainty' (probability = 1.0000).[10] At any rate the table shows that, of the 20 differences shown, 14 are 'certainly not due to chance' in this mathematical meaning of the phrase. For Alpha all the differences except two are 'certainly not due to chance.' One of these two (*A* and *C*) is highly significant, however. The other is the difference between *A* and *B*, which we have already had occasion to doubt since it is reversed in the times of the Otis Tests, in intelligence scores of both Alpha and the Otis Tests, and, as we shall see presently, in reaction times. In the Otis Tests the differences are all less significant because

[10] *Cf.* E. G. Boring, *Amer. J. Psychol.*, 1916, 27, 317; 1917, 28, 456 f.

they are based on only two-fifths as many cases as are the ratios for Alpha. On the face value of the ratios, some very slight doubt attaches to the difference between *D* and *E*, a little more doubt to the difference between *A* and *C*, still more (naturally) to the difference between *B* and *C*, and a very great deal to the difference between *A* and *B*, which was the least significant difference in Alpha.

In general, then, we may conclude that our analysis has demonstrated significant individual differences in time of reaction when accuracy is approximately constant. Among our subjects, *A* and *B* are the fastest and very nearly equal in speed; *C* is a little slower than *A* and *B*, but not much slower; *D*, however, is much slower than *C*, and *E* is much slower than *D*. Our first task of analysis is performed: we have localized the difference of speed as inhering within the item. We have no need then to look for gross or occasional distractions or irrelevancies of thought, nor to appeal to gross introspection. The tendency for a differentiation as to speed appears in the simple intelligent act represented by a single item of Examination Alpha or of the Otis Test.

Reaction Times.—Having localized the speed factor as within the individual item, our next step was to discover whether it would still inhere in some simpler act that might be supposed to be a constituent or a simplification of the intelligent act (the reaction to an item). Here, however, it must be remarked that we had not actually reduced the speed factor to the simplest item, the item of test 4 of Alpha, the 'same-or-opposite' test. In this test the reactions were so rapid that we were obliged to content ourselves with the times for items in groups of five. Nevertheless the implication from the form of the function in this test and from the results of the other tests made it seem probable that we should have found no different result had we had times for the separate items. Now the items of test 4 are very little more involved than controlled associative reactions, and we might have chosen to advance our limit by studying free and controlled association times. It seemed, however, more economical for us to attempt to bracket the locus of the time-difference by choosing

the simple reaction, which we supposed could not possibly be expected to show these individual time-differences.

We used a Sanford chronoscope with a visual stimulus, a black dot that appeared at a circular hole in a screen. All subjects reacted by pressing the key with the right hand, except *D*, who was left-handed and used the left hand. The subjects were given a brief practice in the natural, sensorial, and muscular reactions, and, when it was found that they gave the chacteristic differences in times between these types of reaction, they were given 110 reactions of the muscular (abbreviated) type. We used the muscular type because we wished to take the simplest type of reaction possible in order to be sure of bracketing the time-difference. The first ten trials were rejected, and the remaining one hundred were averaged. The results were as follows:

Subjects	*A*	*B*	*C*	*D*	*E*
Av. reaction time (sigma)	152.8	158.8	154.8	165.6	172.8
Mean variation	10.9	15.7	15.7	12.6	16.4

To our great surprise even inspection shows that these reaction times give individual differences similar to the time-differences obtained in the items of Alpha and of the Otis Tests. The three rank orders are:

Alpha	*B, A, C, D, E.*
Otis Test	*A, B, C, D, E.*
Reaction Time	*A, C, B, D, E.*

There is a significant correlation between reaction time and the time of the test items (with Alpha, .70; with Otis, .90) even when only the rank-orders are considered. The relationship becomes more significant when one remembers that *A*, *B*, and *C*, among whom the inversions of rank occur, are grouped closely in all three measures, whereas *D* and *E* are more widely separated from them in every case.

If we compute the ratios of all the differences in reaction time to their probable errors (*vide supra*), we get the following:

	A	C	B	D
C	1.24			
B	3.72	2.13		
D	9.09	6.35	4.00	
E	12.02	9.38	7.30	4.21

These ratios are not so high as the ratios noted in Table V. for the Otis Test, although both sets of ratios are based on 100 cases. Nevertheless five of them are over six, *i.e.*, it is mathematically 'certain that the differences are not due to chance'; three more show a probability 'that the difference is not due to chance' greater than .98; and only two are small (*B*–*C*, .85; *A*–*B*, .60). If we are to trust common statistics,[11] we must hold that the major differences here are as valid as the differences in times in the intelligence tests.

Some of the more significant data of this paper have been brought together in Table VI. and the rank correlations between the variables of Table VI. are shown in Table VII.

Table VI

Comparative Average Performance of Subjects in Times and Scores in Examination Alpha, in the Otis Test, and in Simple Reaction Times

Subjects	Av. Weighted Time per Item		Average Simple Reaction Time (Sigma)	Score in Standard Time		Score in Unlimited Time	
	Alpha *Cf.* Table IV	Otis *Cf.* Table IV		Alpha (Forms 5 and 6 Added)	Otis (Forms *A* and *B* Added)	Alpha (Forms 5 and 6 Added)	Otis (Forms *A* and *B* Added)
A	155.45	154.40	152.8	386	142	416	142
B	145.94	158.30	158.8	342	131	381	131
C	173.53	170.62	154.8	335	126	377	126
D	217.34	241.55	165.6	319	121	387	136
E	307.90	278.18	172.8	237	119	397	141

In Table VI. one can compare the reaction times with the other measures of time and of time-and-accuracy. Table VII. shows that the reaction times have a high correlation with the

[11] That we may not always trust statistics, especially in the determination of the significance of differences, has already been argued by one of us: Boring, *Psychol. Bull.*, 1919, 16, 335–338. T. L. Kelley has taken the author to task for these remarks in *Amer. J. Psychol.*, 1923, 34, esp. 409–411; but the author sees still no reason to revise his original remarks.

scores (standard time) of both Alpha and the Otis Tests and also with the times in the Otis Tests (all .90), and that the correlation is high though lower with the times of Alpha (.70). We are inclined, therefore, to conclude that reaction time is a very important factor in intelligence as the tests test it, both because of the relation of these reaction times to the important speed-factor as analyzed out of performance in the tests, and also because of their direct relation to the intelligence scores.

TABLE VII

RANK CORRELATIONS BETWEEN TIMES AND SCORES OF TABLE VI, *Q.V.* FOR MORE EXPLICIT INDICATION OF THE NATURE OF THE ITEMS

	Alpha: Av. Time	Otis: Av. Time	Reaction Time	Alpha: Score in Standard Time	Otis: Score in Standard Time	Alpha: Score in Unlimited Time	Otis: Score in Unlimited Time
Alpha: av. time	—	.90	.70	.90	.90	−.20	−.20
Otis: av. time	.90	—	.90	1.00	1.00	.10	.10
Reaction time	.70	.90	—	.90	.90	0	0
Alpha: score in standard time	.90	1.00	.90	—	1.00	.10	.10
Otis: score in standard time	.90	1.00	.90	1.00	—	.10	.10
Alpha: score in unlimited time	−.20	.10	0	.10	.10	—	1.00
Otis: score in unlimited time	−.20	.10	0	.10	.10	1.00	—

In drawing this conclusion we wish, however, to make two reservations. In the first place, we should like to see this experiment repeated with more subjects and more reaction times. We do not trust the application of statistical method unreservedly where the number of cases is small. We were surprised at the finding and only the termination of the academic year prevented us from going further. In the second place, we wish to point out that we are emphasizing facts of central tendency and not of variability. We can not explain why the rank order of *A*, *B*, and *C* is different for the three sets of times except to say that these three subjects were relatively close together in all three series and that their order is reversed by chance variability. It is possible that an increase in the number of cases might yield consistency even

here. On the other hand, it is possible that different time-elements, not common to the different situations, inhere in the variability and still require isolation, since they act concurrently with the central tendency the existence of which is indicated in this section of our paper.

Conclusions

Our results are set forth numerically in Tables VI. and VII. The upper left section of Table VII. indicates that there is a high correlation between score in an intelligence test, speed in an intelligence test, and speed in a simple reaction.

The upper right and lower left sections of Table VII. show that a great lengthening of the time limits for a standard test destroys these correlations, and we have noted in the paper that this result occurs because the faster subjects do not have an opportunity to utilize the additional time allowed. The table does not indicate that the "slow but accurate" subject has any advantage over his more rapid rival in any case where time is at all important. We have observed in the paper that he may have an advantage if time is of no value, but that he does not always have an advantage even then.

In general, we have concluded that speed of reaction is an important, and probably the most important, factor in individual differences in the intelligent act.[12] We find that these differences in speed are not due to gross distractions or irrelevant acts, but inhere in a single item of an intelligence test and probably in so simple an act as the muscular reaction.

In view of this fact we note that intelligence assumes in psychology the rôle of 'power' in mechanics. It would seem to be primarily, although as the tests test it not entirely, mental power. 'Power,' it will be observed, is work done against time; the unit of power is unit work in unit time.[13]

The conception of intelligence as mental power would seem to give new meaning to intelligence as the 'common factor' or as 'general ability.' Spearman's conception of the common factor demands that we conceive all mental acts as involving

[12] *Cf.* Thorndike's analysis, note 7, p. 73, *supra.*

[13] *Cf.* note 3, p. 72, *supra.*

general ability and special abilities.[14] Hence we can test for general ability only as we test so many special acts that the special abilities may be supposed to cancel one another, leaving exposed the net influence of general ability. Power is just such a general factor in mechanical operations. By itself it has no meaning. It is ability to do work against time, and it is exhibited only as it is utilized in some special machine or in some natural mechanism.

It is needless to point out that, if the relation of intelligence (as the tests have tested it) to reaction time of any sort can finally be established, great consequences, both practical and scientific, would follow. Practically we should have a precise and economical way of testing a fundamental and socially important individual difference. Such tests would not yield all the relationships that intelligence tests now do, because current intelligence tests also involve many educational and perhaps other psychological factors. Nevertheless, what we lost in predictive and diagnostic value we should make up in precision and in scientific intelligibility.

Scientifically we should have come already to some knowledge of the nature of intelligence and should be prepared to proceed further. Since we have failed in this study to localize the speed factor by bracketing it approximately at some level of complexity, it might be well to seek to determine next the rate of conduction of the nervous impulse in individuals of different intelligence. We make this proposal, not because we ourselves contemplate it with gravity, but because we think such a result would be no more surprising than would be the final establishment of the relation of reaction time to intelligence. After all we really know very little about the rate of conduction of the nervous impulse, and physiologists have recently discovered that what was supposed to be a constant value may occur at different rates in different fibers of the same nerve; a single stimulus may set up three or even four separate impulses of which the fastest may have a rate three times that of the slowest, as in the case of the sciatic nerve of the frog recently reported by Erlanger and Gasser.[15]

[14] B. Hart and C. Spearman, *Brit. J. Psychol.*, 1912, 5, 51–79; Spearman, *Psychol. Rev.*, 1914, 21, 101–114.

Note.—We take advantage of our proof-sheets to note that Weidensall has already indicated that speed may in some cases be the primary factor in so-called differences of intelligence,[16] and that Bernstein, on the other hand, is said to have found no correlation between quickness and intelligence.[17] Unfortunately Bernstein's monograph is not immediately available to us, so that we remain in ignorance of the method and of the observational meaning of the terms of the title.

[15] J. Erlanger and H. S. Gasser, *Amer. J. Physiol.*, 1924, 70, 624–666. The rate of the fastest fibre was 47 and of the slowest 14 m./sec. In the dog's saphenous nerve they got differences of the order of the difference between 86 and 46 m./sec.

[16] J. Weidensall, The mentality of the criminal woman, *Educ. Psychol. Monog.*, 1916, 14, 279 ff.

[17] E. Bernstein, Quickness and intelligence, *Brit. J. Psychol. Monog.*, 1924.

FURTHER OBSERVATIONS ON THE SPEED OF RETINAL IMPRESSION [1]

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The earlier communications (1, 2) implied in this title treat of the measurement of the duration of visual stimulation necessary, under various conditions, to determine an appropriate response. The general plan has been to establish certain conditions as to the test-object and the surroundings of the field upon which it was seen and then to measure by a suitable method, in which time was the variable, the value of the time-threshold. The plan involved a limited number of subjects and a comparatively long term of experimentation with each, yielding generally ten series for each subject under each set of conditions. The serial group-method was used, each series consisting of ten exposures at each value of a series of graded times.

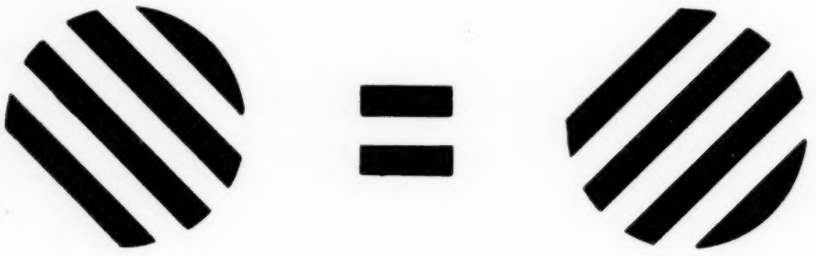
In the work now to be described a different plan was used. Whereas the earlier work yielded only a few time values well above 100σ, most of the averages were much lower, chiefly around 30σ or lower; and it was desired to learn more completely what occurred when the threshold-time of exposure was of longer duration. It was therefore decided to work with a small number of fixed times of exposure, to use brightness as the experimental variable within the series, and to use test-objects, various as to size and contrast, whose visibility thresholds at the durations chosen should occur within the range of brightness which was of especial interest, namely, from about 1 to 100 ml. As a matter of fact, under some of

[1] The first portion (I.) of the experimental work was carried out at the Laboratory of Pure Science, Nela Research Laboratories, under the directorship of the late Dr. Ernest F. Nichols. Credit is due Mrs. Marion Smith Steel for carrying out the greater part of it. The second portion (II.) was done at the Lighting Research Laboratory, under the directorship of Mr. M. Luckiesh, the details being carried out by Mr. Frank K. Moss.

the selected conditions the test-object was visible much below this lower limit; while, under others, its visibility was not attained even at the highest brightness available.

Apparatus and Procedure

The apparatus was arranged as in the earlier work (1, 2). The test-object chosen was of the double bar type (*b*, Fig. 1),



a *b* *c*

Fig. 1. The test-object (*b*) and the pre- and post-exposure patterns (*a* and *c*). The test-object could be shown in the vertical position as well as in the horizontal. First *a* appears, then *b*, then *c*, in the same place. The unit-dimension in this figure is 3.18 mm. ($\frac{1}{8}$ inch).

and was exposed with confusion fields (*a*, *c*) immediately preceding and following it at the same point on the screen. The 'unit' is the nominal dimension hereinafter used to describe the stimulus-complex *a-b-c*. As before, the width of the bar and the width of the intervening space are each 1 unit, the length of the bars in the test-object *b* is 3 units and the diameter of the confusion-pattern 7 units; the stripes and the spaces in these latter being spaced exactly as the bars and spaces of the test object *b*.

Since the brightness was the experimental variable the objects were so made as to give the desired brightness relations when viewed by reflected light, in order to avoid the frequent independent adjustment of more than one lighting device. The central portion of the screen carried a mask, made of heavy tin, with a rectangular opening, 5 cm. wide and just equal in height to the diameter of the confusion patterns *a* and *c*. The test-object was centered behind this opening, as close as possible without interfering with the operation of the two gravity drops carrying the cards on which were drawn the pre- and post-exposure patterns. Of these, the pre-

exposure pattern was drawn with its circular outline tangent to the upper edge of its card. This same edge of the card just coincided with the upper edge of the mask-opening in the initial phase of the exposure *a*, with the pre-exposure pattern therefore just centered in the opening. When the first (lower) drop was released, it carried the card with it out of sight below the lower edge of the opening, thereby exposing the test object *b*. During the next stage (exposure) the second (upper) drop, carrying the card with the post-exposure pattern tangent to its lower edge, rested with the lower edge of the card exactly at the upper border of the mask opening. When this second drop was released it fell, covering the test-object and coming to rest with the pattern centered in the opening. Rebound was prevented by means of a friction stop. The plane of the test-object was $4\frac{1}{2}$ mm. behind the mask, which gave clearance sufficient for the drops to work between with perfect freedom.

The drops were each a small tray made of tin, with three sides only. This left one edge of the bottom free, which was the edge which worked between the mask and the test-object. The card carrying the pattern was in each case attached to the drop with small clips, which permitted ready removal and replacement, with the circular pattern-outline tangent to the free edge. The drops were provided with lugs which worked freely in grooves in a pair of vertical wooden guides. The release was brought about by a double-acting electromagnetic device, which rocked a suitable escapement, first in one direction releasing the first drop, then back, releasing the second. Two switches on the arc of a pendulum timed the two releases, and the second switch was adjusted to a position on the arc which would give the exposure-time desired. For the *ad libitum* exposures, the apparatus was arranged so that the second drop did not fall at all. The two drops were raised together by hand, and the pendulum was released by a key under the hand of the subject when he received the 'ready' signal.

The times of exposure selected were 50σ, 100σ, 200σ and *ad libitum* (T). The experimental program consists of two

separate pieces of work, the second of which was not begun until after the completion of the first. The two sections involved the coöperation of two groups of subjects, composed in part of identical individuals.

I. At first, test-objects and confusion patterns were used which were made by simply drafting the patterns (*a*, *b* and *c*, Fig. 1) with India ink upon white card. The reflection-factor ratio, card to ink, was in this case 100 : 4. Three sizes of these test-objects were used, the unit of the scale being $1\frac{1}{2}$, 2 and 3 mm. respectively.

II. It was desired to get corresponding data for test-objects having lower contrast than the above. The difficulties of preparing test-objects of this sort are many. First, a means must be devised of delineating a form which shall have a uniform reflection factor not greatly different from the ground upon which it shall appear. Secondly, this reflection factor, or at least its value relative to that of the ground, must be measurable and must also be reproducible for the other test-objects of the same series. Since the areas involved are small such measurement has to be made upon a large sample prepared especially for the purpose, and reproducibility becomes a factor of high importance. Thirdly, the effect upon the reflection factors of soiling has to be considered. The change in reflection factor of white and light gray surfaces, brought about by dirt and finger-marks, is surprisingly great; and the resulting change in visibility is presumably much more important than for the case in which the elements are originally white and black, although it is by no means negligible in the latter case.

The expedient finally hit upon consisted in the use, in place of card, of translucent white celluloid (**3**). The test-object and patterns were drawn with India ink upon sheets of this material 0.38 mm. (0.015 inch) thick, and the reverse side was then used, the celluloid being backed by white card. A sample prepared for the purpose showed that the ink so viewed through the thickness of the material had a reflection-factor 0.73 of that of the adjacent uninked celluloid backed by the white card. The contrast in this case was therefore 100:

73. Three sizes of test-object of this contrast were used, the scale-units being 2, 3 and $4\frac{1}{2}$ mm. respectively (4). These proved in the outcome to correspond, as to visibility, with the three high contrast test-objects, each to each, described under I.

The test-object was seen binocularly by the subject, who was seated in an unlighted room, through a rectangular wall-opening 41 by 51 cm at 3 meters' distance. The screen bearing the test-object was 6 meters from the subject. It was more than large enough to fill the wall-opening from the subject's location. No auxiliary fixation-point was used, the eyes being fixated directly upon the area of the test-object.

The screen was lighted by a set of interchangeable systems similar to those previously described (1, 2). With the maximal voltage used (110 volts) the various sets of lamps yielded a series of brightnesses varying by a factor of about 2. In order to get smaller intervals than this for the serial steps, reduced voltages were used on the various sets of lamps, the maximum being 110 (on lamps rated at 115) and the lowest used being 86. The entire brightness range was (in sect. I.) from 141 to 0.021 ml. and (in sect. II.) from 131 to 0.013 ml. By selecting the reduced voltages these ranges were divided into steps forming approximate geometric series, the ratios being unavoidably somewhat unequal and of the order of 1 : 1.37 or 0.73 : 1.

From about 5 ml. down, instead of a pair of lamps at the level of the test-object and somewhat laterally placed on either side, a single lamp was used, placed in the median plane of the apparatus. From about 4 to 0.4 ml. the lamp was hung above the visual line near the partition; and for brightnesses below this the lamp was placed below the visual line, enclosed in a box near the floor. The box was provided with a diffusing light of milk-flashed glass, stopped down as necessary with calibrated cardboard diaphragms. The voltage control for the serial steps was used for the single lamps as for the pairs.

The arrangement of light sources above and below the visual line was objectionable, since this caused one of the horizontal borders of the mask-opening to cast a shadow on the card

bearing the test object. Although readily visible, this shadow was little in evidence on the confusion-patterns owing to their close proximity to the mask; while in the case of the test-object the shadow encroached upon the card only, leaving the test-object fully illuminated as well as a substantial interval on the blank cardboard.

Results

In Section I. of the work (contrast of test-object 100 : 4), thirty-two subjects participated; in Section II. (contrast 100 : 73), thirty. Owing to individual differences some of these failed to yield threshold-values for the more difficult conditions; *i.e.*, for the smaller test objects and for the shorter times. To furnish an estimate of these individual variations, as well as to gain an idea apart from them as to the reliability of the mean results, Table I. was prepared. This includes only those conditions within which every subject (less one, in one case, each section) yielded a threshold-value.

The values given under the column-headings T, 200σ, 100σ and 50σ are the mean logarithms of the brightness in millilamberts for threshold vision of the test-object indicated within the time specified. In each case the number in parentheses is the number of results yielding the average, and the value just below is the standard deviation of the single measurement. In the columns and rows headed "dif." are similarly given the average differences between the log's. brightness for the conditions adjacent in the table. These differences were computed for the individual cases, and their standard deviations (*a* in the table) computed independently.

The measure of precision of a sum or difference is the quadratic sum (square root of the sum of the squares) of the similar measures of the two quantities. On the tentative assumption that all of the variabilities are accidental, the corresponding standard deviations of the differences between the mean log's. have been computed and entered (*b*) below the standard deviations of the mean differences (*a*). From the fact that *b* is always larger than *a*, by a factor of 2 or more, we may draw the conclusion that the differences in the log's. brightness as between any two conditions are less subject to

MEAN THRESHOLDS, STATED AS LOG. BRIGHTNESS, AND DIFFERENCES FOR COMPLETE GROUPS OF (SECT. I.) 32 AND (SECT. II.) 30 INDIVIDUALS

Below each mean log. is given its standard deviation. For the differences these were computed (*a*) directly from the separate differences between the log's. brightness for the individuals and, (*b*) as the square root of the sum of the squares of the standard deviations of the two mean logs. The fact that the latter (*b*) are always the larger indicates that the individual variations are predominantly in the absolute brightness rather than in the differences between one brightness and another. The former (*a*) are made use of in the text to appraise the reliability of the experimental method.

The number in parentheses is, in each case, the number of terms involved in the average. This is the whole number of subjects in the group, except for one case in each section.

Mm.	*T*	Dif.	200σ	Dif.	100σ	Dif.	50σ
			Section I. High Contrast, 100 : 4				
3	(32) 9.14 ± 0.47	(32) 0.28 (*a*) ± 0.25 (*b*) ± 0.69	(32) 9.42 ± 0.51				
Dif.	(32) 0.75 (*a*) ± 0.32 (*b*) ± 0.72						
2	(32) 9.90 ± 0.55	(31) 0.40 (*a*) ± 0.46 (*b*) ± 0.84	(31) 0.24 ± 0.63				
			Section II. Low Contrast, 100 : 73				
$4\frac{1}{2}$	(30) 8.98 ± 0.32	(30) 0.40 (*a*) ± 0.17 (*b*) ± 0.45	(30) 9.38 ± 0.32	(30) 0.26 (*a*) ± 0.18 (*b*) ± 0.48	(30) 9.64 ± 0.36	(30) 0.44 (*a*) ± 0.18 (*b*) ± 0.49	(30) 0.08 ± 0.33
Dif.	(30) 0.52 (*a*) ± 0.23 (*b*) ± 0.53						
3	(30) 9.50 ± 0.42						
Dif.	(29) 0.90 (*a*) ± 0.29 (*b*) ± 0.61						
2	(29) 0.39 ± 0.44						

individual variation than the log's. brightness themselves. This was perhaps to be expected; for presumably under any two conditions as to the test-stimulus, the threshold brightnesses will both be higher or both lower for one individual than for another, according as he required more or less light for an equal result. While it cannot be assumed that the difference is in any particular case free from individual variation, it is still conservative to use the differences rather than the brightnesses themselves as a basis for a measure of the reliability of the experimental method.

From Section I. it appears that the mean of the three standard deviations of the differences is 0.34. The standard deviation of one of the terms, assuming both to have the same reliability, would be $\sqrt{\frac{1}{2}}$ times this or $\pm$ 0.24. Since we are dealing with common logarithms here, the limits corresponding to (mean log.) $\pm$ 0.24 will be numerically as 1.74 and 0.58, where the geometric mean brightness is as unity.

From Section II. (Table I.) the mean standard deviation of the difference is 0.21, the standard deviation of log. brightness computed therefrom is 0.14, corresponding similarly to 1.38 and 0.73 of the mean brightness.

In Fig. 2 are plotted the common logarithms of the threshold brightness for each size of test-object and for each time of exposure, both for the high and for the low contrast test-objects. The reciprocal of the time appears as ordinate and log. brightness as abscissa. Fig. 2*A* gives the actual average log. brightness obtained from ten subjects who gave complete results except, at least, for the smallest object and for the shortest time (50σ). This value for the group was supplied by taking the mean difference between the values of log. brightness for 50σ and 100σ for the same test-object and for the subjects who yielded the necessary results; and adding this difference to the mean log. brightness at 100σ for all subjects in the group *A*. The difference so added and the number of subjects from whom it was derived are indicated in Table II*A*.

Fig. 2*B* shows the results similarly reconstructed for the entire group of 21 subjects who happened to be available for

both sections of the work, and Table II*B*. shows, similarly, how far the results are the actual average results, as well as the basis and the procedure of reconstruction of the missing values.

TABLE II

THE GEOMETRIC MEAN THRESHOLDS, EXPRESSED AS LOG. BRIGHTNESS, FOR ALL CONDITIONS

A. Ten subjects who yielded values at all conditions except as indicated for 50σ exposure time, smallest object.

B. Twenty-one subjects, values reconstructed where results are incomplete, as indicated.

Mm.	*T*	Dif.	200σ	Dif.	100σ	Dif.	50σ
			A. Ten Subjects, Selected				
			Section I. High Contrast, 100 : 4				
3	8.89		9.24		9.44		9.88
2	9.57		9.93		0.36		0.77
1½	0.34		0.62		1.12	(6) .59	1.71
			Section II. Low Contrast, 100 : 73				
4½	8.84		9.23		9.53		0.01
3	9.29		9.84		0.17		0.66
2	0.12		0.68		1.13	(8) .63	1.76
			B. Twenty-one Subjects, Chance Selection				
			Section I. High Contrast, 100 : 4				
3	9.18		9.42	(20) .21	9.63	(16) .49	0.12
2	9.91		0.25	(18) .38	0.63	(13) .46	1.09
Dif.	(19) .77						
1½	0.68	(11) .27	0.95	(11) .55	1.50	(6) .59	2.09
			Section II. Low Contrast, 100 : 73				
4½	8.98		9.36		9.63		0.10
3	9.46	(20) .55	0.01	(19) .33	0.34	(19) .53	0.87
2	0.41	(18) .59	1.00	(15) .51	1.51	(9) .62	2.13

Discussion

It is to be remembered that the ordinates of Fig. 2 are the reciprocals of the threshold times ('speeds'). Plotting the actual times would be embarrassing in those cases (T) where the time was *ad libitum*. As a matter of fact, the responses in these cases appeared to casual observation little, if at all, less

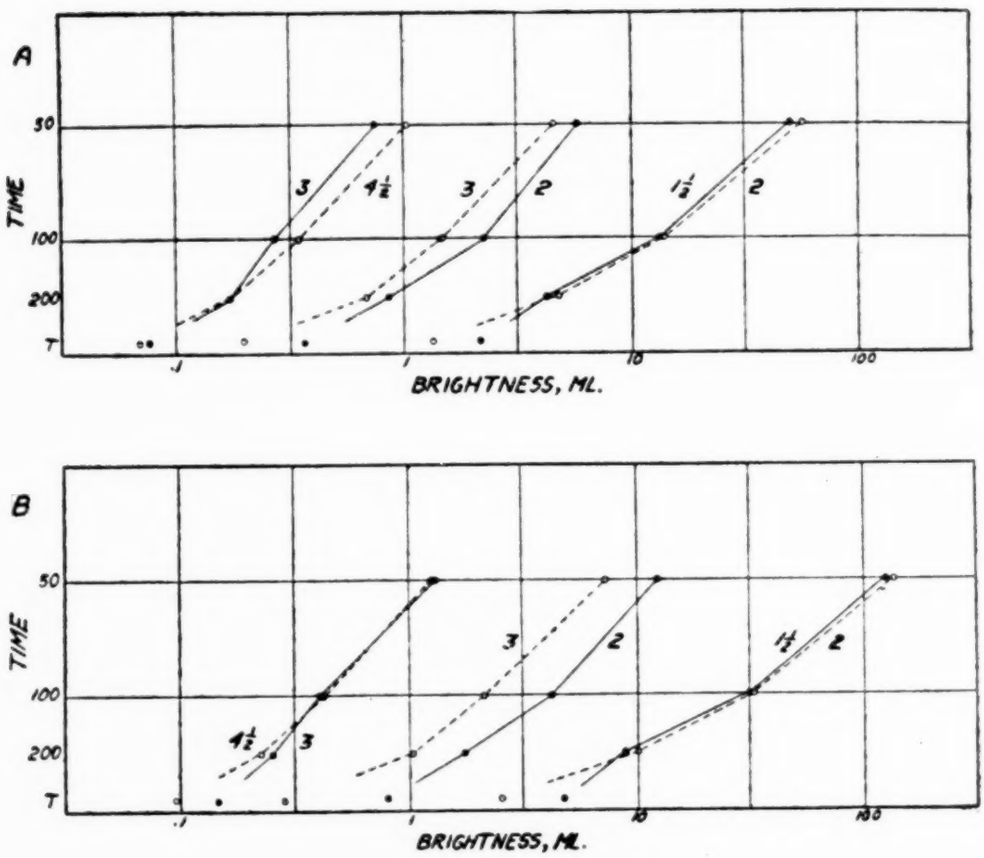


Fig. 2. The brightness of test-object ground required for 50 per cent. correct responses with various times of exposure.

The ordinates are 'speeds' (reciprocal threshold times), assumed to be equal to 1 for *ad libitum* exposure. Abscissæ are plotted as log. brightness, millilamberts. Solid lines and dots indicate contrast 100 : 4, the test object and confusion patterns being drawn with india ink on white card. Broken lines and circles, contrast 100 : 73 patterns drawn on celluloid and reversed (see text).

A. Ten subjects, selected: *B*. Twenty-one subjects, unselected.

prompt than when the time was limited by the falling of the second drop. In other instances there was more hesitancy, sometimes to the extent of several seconds; although this happened now and again when the exposure time was limited.

It would be difficult to indicate upon a plot the fact that a value was somewhere between, say, 200 and infinity. By plotting 'speeds,' on the other hand, it is possible to indicate the results. In the figure the results for the *ad libitum* exposure have been plotted *as if* the time averaged 1 second ('speed' = unity); and the curves have been drawn toward, but not to, this point. This fact must be remembered in the study of Fig. 2.

Inspection of the figure shows that in general the relation between 'speed' and log. brightness is not far from linear. A straight line on the plot would indicate that each multiplication of the brightness by a constant factor afforded an equal increase in 'speed.' But not only do the lines in the plot show a slight curvature, with the concavity upward, but the curves for the different test-objects show in general different slopes for the same time differences; in the sense that the smaller test objects require a larger factor of increase in brightness than the larger (5). The same is true when the contrast becomes smaller, comparing, for example, the two curves for the 2 mm. test-object (Fig. 2*A*). In fact it appears to be true that reducing the contrast from 100 : 4 to 100 : 73 (that is, from white and black to white and gray) is almost exactly equivalent to reducing the size of the test-object by one step in the series $4\frac{1}{2}$, 3, 2, $1\frac{1}{2}$. On the other hand, when the test-object is made more difficult by decreasing the time of exposure, it would appear from the curvature of the lines in the figure that successive increments in "speed" thereby made necessary are accomplished with the help of light increased by successively smaller factors.

Some of the conclusions just stated will perhaps appear more definitely from a study of Fig. 3. *Aa* and *Ba* show the relations found between the dimensions of the test-objects and log. brightness, for the various exposure-times and for both contrasts. In so far as the comparison is possible, the curves indicate that *ad libitum* exposure with the low contrast is equivalent to something between 100σ and 200σ with the high; and that 200σ with the low is equivalent to slightly more than 50σ with the high. In the latter case

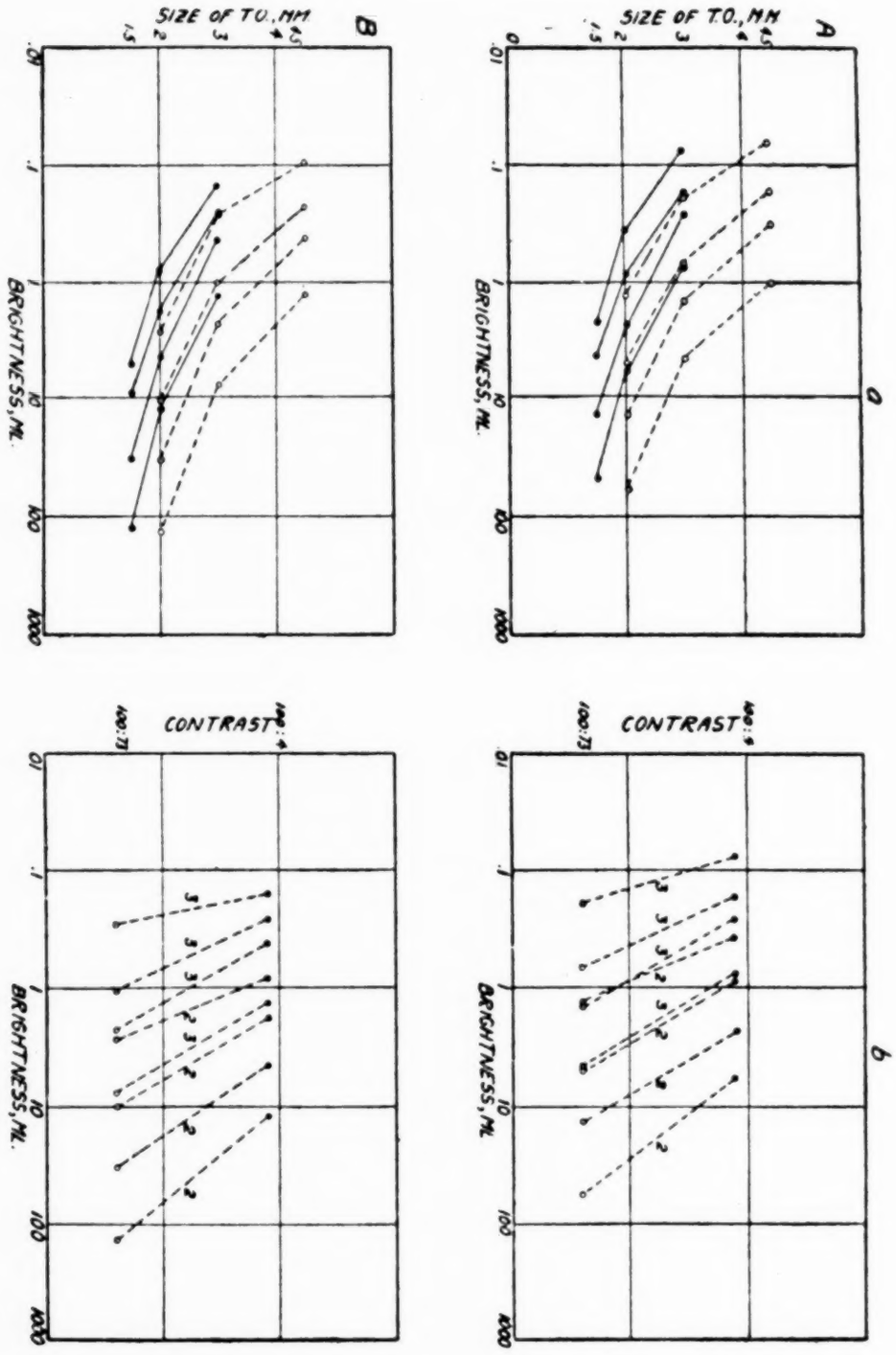


FIG. 3. (*a*) The relation between the size of the test-object and the threshold brightness. (*b*) The relation between contrast and brightness for the 3 and 2 mm test-objects.

High contrast is indicated by the dots, low contrast by the circles. In each family of four curves, the times of exposure are *ad libitum*, 200, 100, and 50σ, respectively, from left to right. A and B, ten and twenty-one subjects respectively as before.

the result of changing to the low contrast has been to make necessary nearly a fourfold increase in the exposure time. *Ab* and *Bb* of Fig. 3 show the relation between contrast and brightness, for the 3 mm. and the 2 mm. test-objects, which are the only ones comparable in this way. The increment of log. brightness necessary to offset the lowered contrast is seen to be larger the smaller the test-object and the shorter the time of exposure.

It remains to draw a comparison between these results and those of an earlier communication (**2**). Of the latter, there is one set which is comparable to certain of the present sets. Four subjects participated, only one of whom is included in the group here concerned. The test-object was of the same design, but the unit-dimension was 3.18 mm. ($\frac{1}{8}$ inch) instead of 3 mm. exactly, and it was preceded and followed by similar

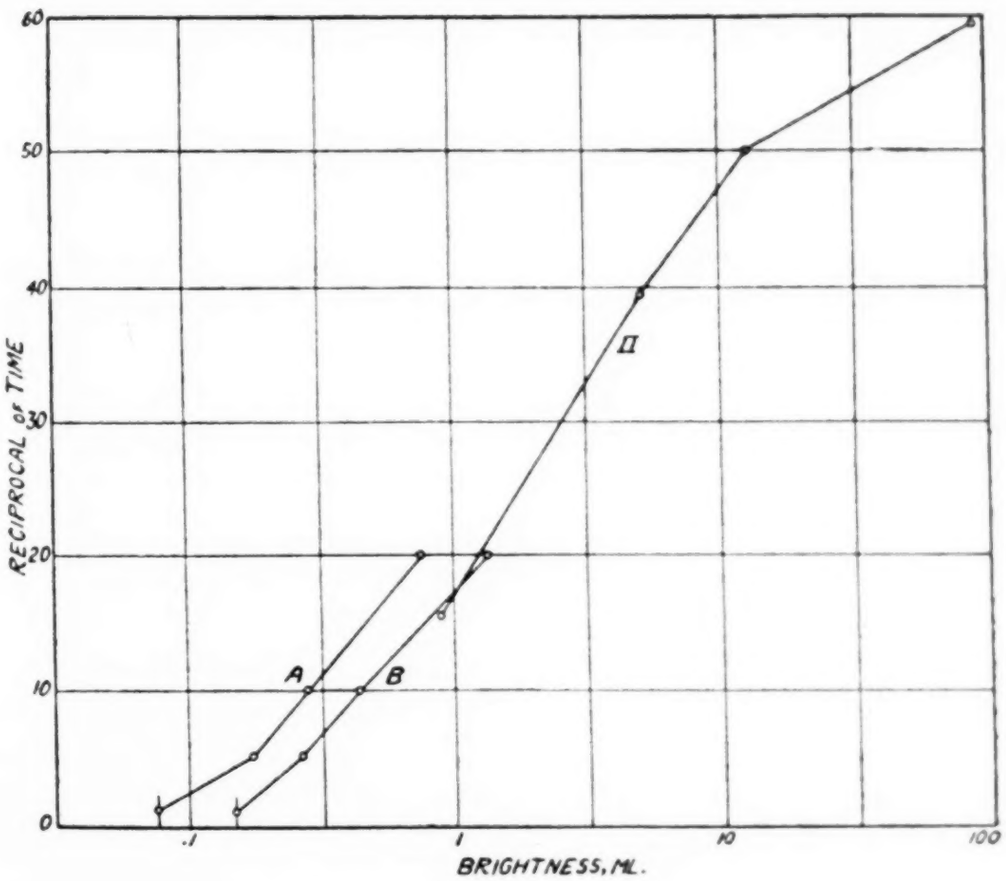


FIG. 4. The results for the 3 mm., high contrast test-object (*A*, *B*) compared with previous results (II.) obtained with a 3.18 mm. ($\frac{1}{8}$ inch test-object of like design). Curve II. embodies the same results as Curve II., 4, Fig. 11, this JOURNAL, 1925, *8*, 95.

confusion-patterns. These earlier results are plotted in Fig. 4, to the same coördinate scales as are used in Fig. 1, and on the same plot are reproduced the curves from Fig. 1, *A* and *B* (3 mm. test object, high contrast) for 10 and for 21 subjects respectively. The latter, as will be seen, meets the curve from the earlier work, while the former parallels it at a somewhat lower brightness.

It is to be remembered that aside from representing different groups of subjects the results intercompared were taken by different methods. In the earlier experiments fixed levels of brightness were used and the exposure-time was the experimental variable actually measured; while the reverse was the procedure for the present work. Furthermore, in the present work fixation was directly upon the test-object, while in the earlier the test-object was 2° to the right of the fixation-point. The comparison shown in Fig. 4 nevertheless would seem to indicate that the essential differences between the two sets of results are by no means radical.

Summary

1. The work described in this paper is a continuation of earlier experiments, in which the relations between the brightness of a visual object and its time of exposure are investigated as they exist at the threshold. As before, a simple test object is used, preceded and followed at the same point in the visual field by confusion-patterns.

2. This work differs from the earlier work in several essential ways:

(*a*) Larger groups of subjects were employed, each one being engaged for a much shorter time. As a rule, therefore, these individuals were less experienced with the experimental technique than before.

(*b*) For this reason they were instructed to fixate the test-object directly, instead of fixating an auxiliary mark 2° to the left of the test-object, as before.

(*c*) Conditions involving longer times of exposure were investigated. This made it advisable to use fixed times of exposure, and to make brightness the immediate experimental variable. In the interests of expediency, certain modifications in the apparatus were incidentally made.

(*d*) In addition to the white and black test-objects formerly used, a new group of test-objects was introduced having a lower contrast between the figure and the ground upon which the figure appeard.

3. In general, the effect of changing from the higher to the lower contrast (from 100 : 4 to 100 : 73) was about equal to the effect of reducing the size of the high contrast (100 : 4) test-object one step in the size-series: 3, 2, 1½ mm. Thus the test-object, disregarding for the moment the factor of time, could be made more difficult in either of two ways.

4. For any given test-object it was found that the "speed" (reciprocal of the threshold-time of exposure) increased approximately in proportion to the logarithm of the brightness; the exception being that, if anything, at higher speeds (time reduced from 100 to 50σ), the same increment in speed was accomplished with a somewhat less than proportionate increase in brightness. This was perhaps more strictly true of the more difficult test-objects, the times of exposure varying from *ad libitum* to 50σ.

5. Increasing the difficulty of the test-object by reducing either its contrast or its dimensions had the effect that the identical increase in speed was accomplished only with the help of a relatively larger increase in brightness. That is to say that the general slope of the curve, plotted as in Fig. 2, became less.

References and Comments

1. This Journal, 1923, *6*, 138–160.

2. This Journal, 1925, *8*, 77–108.

3. This material was furnished by the courtesy of the E. I. du Pont de Nemours and Company. Its trade-name is 'Pyralin.'

4. The distances 1½, 2, 3 and 4½ mm, as seen from 6 meters, subtend respectively 0.86, 1.15, 1.72 and 2.58 minutes' angle at the subject's eyes.

5. This fact may appear to stand in contradiction to certain conclusions that have been stated elsewhere; *e.g.*, Luckiesh, Light and Work, (Van Nostrand, New York, 1924) p. 191; Ferree and Rand, *Tran. Illum. Eng. Soc.*, 1922, *17*, 76. These conclusions are to the effect that a relatively greater increase in speed of vision arises from the same increase in light when a more difficult test-object (smaller or of lower contrast) is in question. It will be evident, however, that these statements refer to an identical increase in illumination with different initial speeds; while the statement in the text above refers to identical changes in speed which take place within widely separated ranges of brightness. No contradiction whatever is involved, as will be seen from a study of Fig. 1 with this distinction in mind.

THE ABILITY OF CHINESE STUDENTS TO READ IN VERTICAL AND HORIZONTAL DIRECTIONS [1]

BY L. K. CHEN AND H. A. CARR

University of Chicago

This experiment is concerned with the relative facility with which Chinese students apprehend reading materials arranged in vertical and horizontal columns. The experiment made use of the reading of textual materials and the cancellation of certain characters.

The reading materials consisted of two passages of Chinese prose (in Chinese characters) of approximately the same length and degree of difficulty. Each of these passages was mimeographed in vertical and horizontal columns. The subjects were requested to read a passage through twice, as quickly and as carefully as possible. The time required for this task was recorded in seconds. The subjects were then requested to give an oral reproduction of the material. Each passage was divided into eighty-three logical items, and each subject was scored on the basis of the number of these items correctly reported. Each subject was tested for one passage with the vertical arrangement and the other passage with the horizontal arrangement. Four groups of subjects were employed, and the order of testing the groups was so arranged as to compensate for practice and any difference in the difficulty of the two materials.

The materials for cancellation included Chinese characters, English letters and Arabic numerals. Each material was mimeographed with the two arrangements, but the subjects were required to cancel different characters in the two cases. The order of testing the four groups was so arranged as to eliminate the effects of practice and any differences of difficulty. For each material, the subjects were requested to

[1] From the Psychological Laboratory of the University of Chicago.

cancel two specified characters with maximal speed and accuracy. The time required for each task was recorded in seconds, and each individual was scored in terms of the number of items correctly checked.

Sixty-four Chinese students were individually tested. They were divided into four groups of approximately equal numbers on the basis of the order in which the tests were taken.

The average values per individual for the four groups and for each of the various tests are given in Tables I. and II. In

TABLE I

AVERAGE TIME RECORDS PER INDIVIDUAL

Group	Reading Chinese		Cancelling Chinese		Cancelling English		Cancelling Numerals	
	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.
1.....	84	95	81	88	82	66	65	59
2.....	105	114	87	92	74	66	79	65
3.....	113	131	93	100	78	70	77	71
4.....	92	105	82	88	77	69	75	69

the first table the values represent the number of seconds required for each task; hence the smaller values indicate the greater speed. The values in the second table represent the number of items correctly reported or checked; and in this case the larger values represent the greater accuracy or efficiency. The values for the vertical and horizontal arrangements for each test are given in adjacent columns to facilitate ease of comparison.

TABLE II

AMOUNT OF WORK CORRECTLY DONE

Group	Reading Chinese		Cancelling Chinese		Cancelling English		Cancelling Numerals	
	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.
1.....	53	47	21	20	35	36	32	34
2.....	57	56	22	21	34	35	34	36
3.....	48	46	22	21	34	36	35	37
4.....	45	41	21	20	33	35	35	36

These group results are convincing and unambiguous. Each of the four groups read and cancelled Chinese characters with greater speed and accuracy when they were arranged in vertical columns, while better results were invariably achieved when the English letters and Arabic numerals were arranged in horizontal sequence.

The majority of the individuals in each group conformed to the group-preference in each of the eight comparisons with but one exception; viz., Group 1 in the test for accuracy in cancelling numbers. Eight of these sixteen individuals gave better records for the horizontal arrangement; six did better with the vertical arrangement, and two did equally well in both.

Similar results are obtained when the four groups are regarded as a unit. Ninety per cent. of the individuals read, and eighty-nine per cent. cancelled, Chinese characters faster with the vertical arrangement, while ninety-five per cent. cancelled English letters and ninety-four per cent. cancelled Arabic numerals faster with the horizontal arrangement. The corresponding percentages for accuracy are sixty-nine, sixty-two, sixty-one, and sixty respectively.

The majority of the individuals in each group conformed to the group norm in all four of the tests for speed, or—regarding the groups as a unit—seventy-five per cent. of the individuals conformed to the group-averages in all four tests for speed. The individuals are less consistent with respect to accuracy; for here only twenty-eight per cent. of the total number of individuals conformed to the average group-results in all four tests.

There is no convincing evidence that the preference of these individuals for the vertical arrangement of Chinese characters is stronger than that for the horizontal arrangement of English materials. While the gross differences between the group-averages for the two arrangements of Chinese characters are generally larger than those for the English materials, the comparative results are quite similar when stated in relative or percentage terms. Moreover, there is but little difference in the number of individuals who consistently exhibit the two types of preference.

These preferences are more pronounced for speed than for accuracy. The differences between the group-averages for the two arrangements with respect to speed are larger, both absolutely and relatively, than those for accuracy. On the basis of speed, a considerably larger percentage of the individuals manifest the two preferences than is the case when their performances are measured in terms of accuracy (see above).

These factual results justify the conclusion that the majority of these Chinese students apprehend Chinese characters more quickly and accurately when they are vertically arranged, while they apprehend English materials more readily and correctly when they are arranged in horizontal order. The two preferred arrangements, however, are much more conducive to speed than to accuracy of apprehension.

As has been indicated, there are numerous exceptions to these two preferences. Some of these may be due to chance factors, some to differences of difficulty of the two materials, and others to the order of presentation. A few of these exceptions are so striking that they are suggestive of individual differences. For example, one individual invariably made better records with the horizontal arrangement of the Chinese characters.

TABLE III

RELATION BETWEEN LENGTH OF TRAINING IN ENGLISH AND THE NUMBER OF EXCEPTIONS TO THE GROUP NORM

No. of Subjects	No. of Exceptions	Residence in America (Yrs.)	Training in English (Yrs.)
6	4 or 5	8.16, P.E. .98	12.16, P.E. .69
14	3	4.85, P.E. .42	10.57, P.E. .48
17	2	3.23, P.E. .20	8.64, P.E. .27
13	1	3.84, P.E. .32	7.84, P.E. .25
14	0	3.00, P.E. .28	7.07, P.E. .27

The suggestion that many of these exceptional results are due to individual differences is supported by the fact that the number of exceptions per individual is correlated to some extent with length of residence in America and the number of years in which English has been studied. Table III. gives the

number of individuals who deviated from the group norm in a specified number of the eight tests, together with the corresponding average number of years' residence in America and the average length of time in which English has been studied.

Fourteen subjects deviated from the group norm in three of the eight tests, and these individuals on the average have studied English for 10.57 years and have lived in America for 4.85 years. Forty-four subjects gave exceptional results in less than three of the eight tests, and these individuals have studied English and have lived in America for a considerably less time than the twenty individuals who deviated from the group norm in three or more of the tests.

Undoubtedly, the number of deviations from the group norm is directly correlated with length of residence and amount of training in English.

TABLE IV

RELATION OF LENGTH OF TRAINING IN ENGLISH AND ABILITY TO READ CHINESE IN VERTICAL COLUMNS

No. of Subjects	No. of Exceptions	Residence in America (Yrs.)	Training in English (Yrs.)
5.....	3 or 4	10.50, P.E. .31	14.60, P.E. .27
12.....	2	4.66, P.E. .38	10.33, P.E. .50
17.....	1	2.94, P.E. .23	8.33, P.E. .26
30.....	0	3.33, P.E. .19	7.66, P.E. .19

The corresponding data for the deviations from the group preference for the vertical arrangement of Chinese characters and for the horizontal arrangement of English materials are listed separately in Tables IV. and V. respectively. These tables state the number of exceptions in the four tests. For example, twelve individuals deviated from the normal preference for the vertical arrangement of Chinese characters in two of the four tests, and thirty-two subjects did not conform to the group-preference for the horizontal arrangement of English materials in but one of the four tests.

There is a direct correlation, with one exception, between the number of deviations from the group-preference for the vertical arrangement of Chinese characters and length of

residence and number of years devoted to the study of English. Moreover, the degree of correlation is apparently the most pronounced for those with the greater amounts of training in English. In other words, a considerable amount of training in English enables these students to apprehend Chinese characters as readily with one arrangement as with the other.

TABLE V

RELATION OF LENGTH OF TRAINING IN ENGLISH AND ABILITY TO READ ENGLISH WITH A HORIZONTAL ARRANGEMENT

No. of Subjects	No. of Exceptions	Residence in America (Yrs.)	Training in English (Yrs.)
13.....	2	4.30, P.E. .54	9.46, P.E. .47
32.....	1	4.12, P.E. .25	9.12, P.E. .28
19.....	0	4.00, P.E. .41	8.21, P.E. .45

There is also a direct but small correlation between the number of deviations from the normal preference for a horizontal arrangement of English materials and the length of training in English. The differences between the averages are too small to be of much significance. Taken at their face value, however, these results lead to the somewhat surprising conclusion that the relative ability of these Chinese students to apprehend English materials in the horizontal direction actually decreases to some extent with practice.

It has frequently been suggested that the preference of the Chinese for the vertical arrangement of their characters is ultimately due to some constitutional condition of the eyes that enables them to apprehend materials more easily and readily when they are arranged in this fashion. It is at once evident that the influence of such a hypothetical condition can readily be overcome by training, inasmuch as these students can read English with a greater facility when it is printed in horizontal columns.

It may be suggested that the best arrangement is a function of the materials; that the Chinese characters are so constructed that they can be more readily apprehended when they are arranged in vertical columns. Such an hypothetical influ-

ence can be overcome by training, for a number of these Chinese students who have had considerable training in English can read Chinese as well or better when the characters are horizontally arranged.

Our facts can be wholly explained in terms of habit and training. The concept of habit nicely accounts for the fact that the majority of the individuals did better with the vertical arrangement of Chinese characters and with the horizontal arrangement of the English materials; while the individual deviations from the normal preferences can be explained in terms of conflicting habits.

Those individuals with the least amount of training in English made better records with the vertical arrangement of Chinese characters and with the horizontal arrangement of English letters and Arabic numerals. We have on the one hand the thoroughly established habit of reading Chinese characters with the vertical arrangement with but little opportunity for disintegration through disuse, and on the other the newly developed habit of reading English in the horizontal direction that is incapable of functioning with any high degree of speed and precision. Under these conditions, the two habits function with a minimal amount of conflict and interference.

At the other extreme, those individuals with the maximum of training in English do as well or better with the horizontal arrangement of Chinese characters. In this case the habit of reading in the horizontal direction has become thoroughly established, and the habit of reading in the vertical direction has become somewhat weakened by disuse. In other words, the habit of reading English when thoroughly established becomes somewhat generalized and interferes with, or tends to suppress, the older habit of reading in the vertical direction.

Finally, those individuals with a moderate degree of training in English experience a certain amount of difficulty with the vertical arrangement of Chinese characters as compared with those with the lesser training in English, and the facts, though not entirely convincing, indicate that these

same individuals can not read English when horizontally arranged with the same relative facility as can those with less training. Under these conditions of relative strength, the two habits conflict and mutually interfere with each other. This hypothesis is at least suggestive from the standpoint of the study of the mutual relations of two antagonistic habits.

A COMPARATIVE STUDY OF STYLUS MAZE LEARNING BY BLIND AND SEEING SUBJECTS

BY HELEN L. KOCH AND JENNETTE UFKESS

University of Texas

The purpose of the study was to check with more adequate controls with respect to age, intelligence, and number of subjects some incidental observations made a few years ago by one of the authors upon the maze-learning of the blind. These observations, which are quoted by Dr. H. A. Carr in "The influence of visual guidance in maze learning," [1] indicate that the usual maze presents to the blind more difficulties than to those with normal vision. This result is distinctly contrary to *a priori* judgment, for a stylus-maze was employed which all of the subjects mastered without the aid of vision; and we are likely to argue in this case that the blind, who make so many of their spatial adjustments on a tactual-kinæsthetic-motor plane, will find little that is novel or difficult in the maze problem; whereas the normal subjects, deprived of the visual cues upon which they are wont heavily to depend, will be considerably disturbed. We tend to overlook, however, the possibility that the mere fact of visual experience may provide a more adequate system of spatial symbols than does the sensorially more restricted experience of the blind. These action-patterns developed through vision may function, in other words, to overbalance any handicap to the normal subject in the maze resulting from his usual modes of reacting.

The blind subjects, 19 in number, who served in the present investigation constituted the adolescent group in the Texas School for the Blind at Austin. The ages, as indicated in Table III., range from 14 to 26 years. Some of the subjects have not been totally blind from birth, and some even now possess what is known as 'shadow vision.' A description of the visual capacities of each subject is given in Table I.

[1] This JOURNAL, 1921, *4*, 399–417.

TABLE I

YEARS AND TYPE OF VISUAL EXPERIENCE BEFORE ONSET OF BLINDNESS

Subj.	Description of Visual Experience
[illegible]-6B	All totally blind from birth.
[illegible]PB	Detail vision for 6 years, then total blindness.
[illegible]PB	Detail vision for 3 years, then total blindness.
[illegible]PB	Shadow vision for 14 years, then total blindness.
4PB–8PB	Detail vision for 7, 12, 3, 9, 5 years (resp.), then total blindness.
[illegible]PB	Shadow vision for 13 years, then total blindness.
[illegible]PB	Detail vision for 8 years, then total blindness.
11PB	Shadow vision, never total blindness.
12PB	Shadows and gross details for 17 years, then total blindness.
13PB	Detail vision for 15 years, then total blindness.

Those individuals who have not always been deprived of their sight are valuable for our analysis, since not only do they furnish us an interesting intermediate to the extreme groups—*i.e.*, those with average vision and those with complete life-long blindness—but they also enable us roughly to gauge the effect of varying degrees of visual experience.

The 20 normal subjects were selected from at least 100 senior-high-school and university students, as those who paralleled most successfully in age and intelligence the blind group. All but 5 of the 20 are high-school students. The age range of the normal subjects is from 14 to 32 years.

An approximate pairing of the two groups on the basis of age and intelligence was deemed advisable, first, because of results like those of Hunter[2] and of Warden,[3] which indicate a correlation of moderate degree between skill in the mastering of mazes and performance in the intelligence-test; and, secondly, because the blind group, taken *en masse*, may perhaps be suffering some intellectual handicap as a result of the general physical and nervous disabilities produced by the same factors which mediated their visual defects. Table II. suggests that the caution was justified for, in the case of both blind and normal subjects, homogeneous and small though the groups were, a consistent, medium-sized, negative correlation [4]

[2] Hunter, W. S., Correlation studies with the maze in rats and humans, *Comp. Psychol. Monog.*, 1922–23, I, no. 1, pt. ii, 37–56.

[3] Warden, C. J., The relative economy of various modes of attack in the mastery of the stylus maze, This JOURNAL, 1924, 7, 243–276.

[4] The Pearson product-moment method of computing correlation was used throughout this study.

TABLE II

CORRELATIONS OF AGE AND INTELLIGENCE-TEST SCORE WITH EACH OTHER AND WITH MEASURES OF MAZE PERFORMANCE. BLIND AND NORMAL GROUPS

Group and Factor Correlated	Age	Intelligence-Test Score	Trials (Maze)	Errors (Maze)	Time (Maze)
Age (Blind Group)		+.06±.15	+.12±.15	+.09±.15	−.08±.15
Age (Normal Group)		−.09±.14	+.53±.10	+.31±.13	+.24±.13
Intelligence-Test Score (Blind Group)	+.06±.15		−.44±.13	−.39±.13	−.47±.12
Intelligence-Test Score (Normal Group)	−.09±.14		−.19±.14	−.40±.12	−.39±.12

is shown between intelligence-test scores and the difficulty experienced in mastering the maze, as represented by the trials or time consumed or by the errors accumulated. The correlations tend to be slightly greater in the case of the blind group than they are in the normal, probably because the former is somewhat less homogeneous than the latter. Our results, then, in general bear out the results of Hunter and of Warden.

In our blind group, age and maze success do not seem so closely related as do intelligence and the latter, the subjects being practically adult. The positive correlations of moderate size in the case of the normal group between age and the criteria of skill in maze performance, or rather lack of skill as our data are presented, are, doubtless, the result of the method of selecting these subjects. Most of them were juniors taking chemistry in the summer session of the senior-high-school. Since attendance at summer sessions is usually conditioned either by dullness or failure during the year or by unusual interest, success, ambition, etc., we should expect the younger subjects to be generally better equipped from the point of view of intellect than the older ones. The slight negative correlation between age and intelligence supports this hypothesis.

Since no adequate intelligence tests for the blind adolescents or adults were available, the authors found it necessary to adapt to their needs one of the standard group-tests. They are fully aware that in their adaptation the character of the test has been altered and that probably the claims made for the tool as a measure of intelligence in its original standardized form are no longer entirely applicable. Certainly the speed factor was to a large extent eliminated, since the problems were necessarily presented orally, and the subjects at least had (so to say) a chance at every task. It is well to note, also, that while both blind and normal subjects use their

aural mechanisms in their daily lives, still the auditory presentation of the material may have offered an unfair handicap to one of the groups. On this point we have no check.

As arguments, however, for the merit of the instrument used by us to measure intelligence let us say, first, that among the 100 normal subjects examined, the university students (mostly sophomores) outstripped the high-school students (mostly juniors) by an average of 20 points, and, secondly, that the correlation between the scores made on our adaptation of the Army Alpha Test by the high-school students (normal group) who served in the maze experiment and the following criteria of intelligence: (*a*) score on the Miller Mental Ability Test, (*b*) the instructor's rating of intelligence, and (*c*) final grades in chemistry were, respectively, + .88 ± .04, + .80 ± .06, and + .44 ± .11.

The test given included all or parts of the following six sub-tests of the Army Alpha (Form 9): the arithmetic, opposites, analogies, number-completion, information, and best-answers. All of the best-answers, opposites, and analogies tests were employed, as were also 16 of the arithmetic problems, 38 of the information, and 15 of the number-completion. Those tests given in part were not completed because their more difficult sections were so far beyond the capabilities of the blind subjects that a recital of them had the effect of completely discouraging the experimental group and of ruining its morale.

Of the 100 university and high-school students who took the test and from among whom our subjects were selected, no one amassed more than 142 points. For the individuals whose performances are reported in this study 118 is the maximal score.

The test was given rather informally to the blind, but still with adherence to most of the details of procedure usually observed. The problems were generally read aloud twice; and, if the group indicated a desire for a third reading, this also was given. Only when the blind subjects showed by their attitude that they had either completed an attempted solution or were unable to solve the problem was the next task presented. This method of administration makes of the test an achievement rather than a speed test. The test as conducted with the blind subjects furnished the standard of procedure for the normal group in regard to such details as instructions, time allotted for each individual problem, etc.

The blind subjects used the Braille apparatus or the typewriter to record their answers, which in each case consisted of a response no more complex than a word, and usually merely a letter or number. The normal subjects wrote their answers with a pencil. How significant an effect this difference in routine may have had we do not know with certainty, though we question, since speed played so small a part in the performance, whether the variation is of any great moment.

The blind group was handled by one experimenter; the normal, by the other. The authors attempted to prevent the personal equation from being introduced as a prominent factor into the results by carefully working over together the details of the administration of both of the tests.

The maze used was a metal stylus maze designed by Dr. Koch,[5] (see Fig. 1) and the general method of conducting the

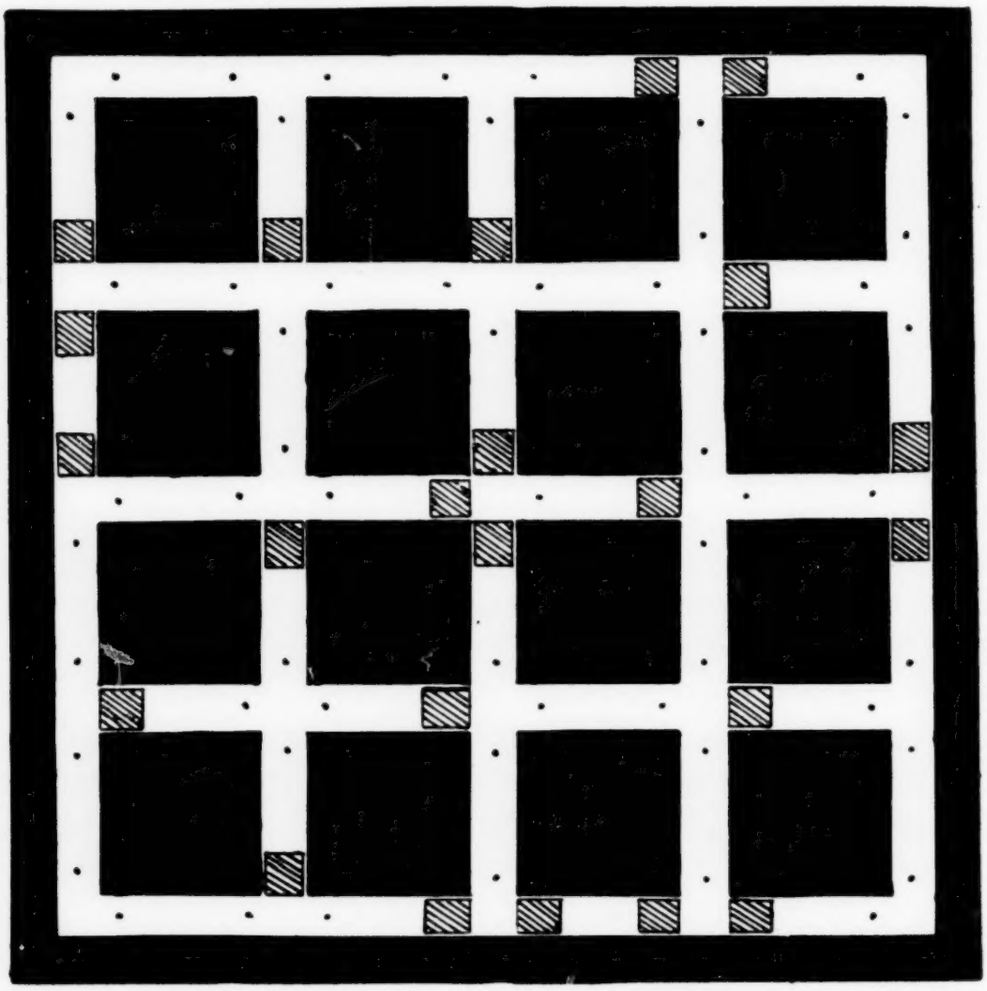


FIG. 1

[5] This maze has two noteworthy characteristics: (1) the ease with which the distance traversed in it by the learner can be estimated; and (2) the multiplicity of different patterns which it affords. The distance covered can be estimated sufficiently accurately for group comparisons, at least, by merely counting the number of blocks passed by the learner en route to the goal and multiplying this count by the length of one block, as all the alley-ways are divided into segments of equal length.

maze experiment was the same as that described in her monograph, "The influence of mechanical guidance upon maze learning."[6] The canopy which screened the maze from the view of the normal subjects was employed in the case of the blind subjects also, in order to keep the tactual-kinæsthetic situation as nearly identical as possible for the two groups. Time was recorded with a stop watch. A standard of mastery of three successive perfect trials was arbitrarily adopted.

Tables III. and IV. show the maze performance of the blind (as measured by the three criteria, time, trials, and

TABLE III

AGES, INTELLIGENCE-TEST SCORES, AND MEASURES OF MAZE PERFORMANCE. BLIND SUBJECTS

Subj.	Age	Intelligence-Test Score	Trials (Maze)	Errors (Maze)	Time (Sec.) (Maze)
1PB	16	65	9	33	341
2PB	16	72	6	32	493
3PB	16	98	8	85	1267
4PB	21	97	7	59	550
5PB	26	96	9	20	184
6PB	18	115	15	24	120
7PB	20	79	20	32	460
8PB	15	58	9	142	824
9PB	18	58	119	395	3493
10PB	21	90	7	6	144
11PB	18	94	5	78	525
12PB	18	—	5	12	152
13PB	14	99	5	9	146
1B	20	67	27	86	1055
2B	20	72	142	1056	5977
3B	21	98	15	52	359
4B	16	104	20	53	443
5B	16	117	9	25	205
6B	20	—	23	67	728
Median	18.0	94.0	9.0	52.0	460.0
Mean	18.4	87.0	24.2	119.3	919.3
σ Distribution	2.94	18.3	37.21	236.2	1403.4
P.E. Mean	.45	2.83	5.76	36.5	217.1

A very great variety of maze patterns is made possible by the employment of metal pegs at the junctions of the various run-ways. The dots in Fig. 1 indicate the holes in the floor of the maze into any one or group of which the pegs may be inserted. Since the pegs fit snugly and are always set in flush with the walls of the run-ways the subject is unlikely to be disturbed by any roughness or break in a wall which the experimenter desires to be continuous. The positions of the pegs in the maze pattern employed in the study are indicated in the diagram by cross-hatching.

[6] *Psychol. Monog.*, 1923, *32*, no. 147. Pp. vi + 113.

TABLE IV

AGES, INTELLIGENCE-TEST SCORES, AND MEASURES OF MAZE PERFORMANCE. SUBJECTS WITH NORMAL VISION

Subj.	Age	Intelligence-Test Score	Trials (Maze)	Errors (Maze)	Time (Sec.) (Maze)
1N	15	79	10	74	1569
2N	20	75	9	57	525
3N	16	100	4	18	175
4N	14	96	7	10	203
5N	17	104	10	9	189
6N	15	118	8	18	450
7N	17	81	29	52	755
8N	17	56	20	66	1487
9N	16	84	12	47	751
10N	18	89	16	33	429
11N	16	92	12	24	298
12N	16	84	14	22	185
13N	17	92	11	26	391
14N	32	87	57	81	1132
15N	16	92	25	89	662
16N	21	97	3	14	231
17N	28	84	8	16	233
18N	22	93	70	144	1563
19N	16	102	3	7	119
20N	18	102	8	21	317
Median	17.0	92.0	10.5	25.0	410.0
Mean	18.3	90.4	16.8	41.4	583.2
σ Distribution	4.53	12.23	16.98	34.30	470.9
P.E. Mean	.60	1.85	2.56	5.18	70.9

errors) to be inferior to that of the normal subjects, the two groups differing most in respect to their error scores. This relation was likewise observed in our earlier work. None of the group-differences, to be sure, are statistically significant, if a ratio of 3 or more between the difference of the means and the probable error of this difference is accepted as an index of reliability. We may question, however, the use of this index with a few cases. The consistency of the results and their close agreement with our earlier observations merit confidence in their representativeness of what would occur were many more subjects employed.

One may press the question further and note too that, while the blind are almost of the same average age as those with normal vision, they have a very slightly lower intelligence average. The medians, on the other hand, show a reversal of these conditions. A later and more analytical presentation of the data (see Table VII.), moreover, suggests that these small differences in age and intelligence do not destroy the validity of the tendencies shown by the criteria of skill in maze learning.

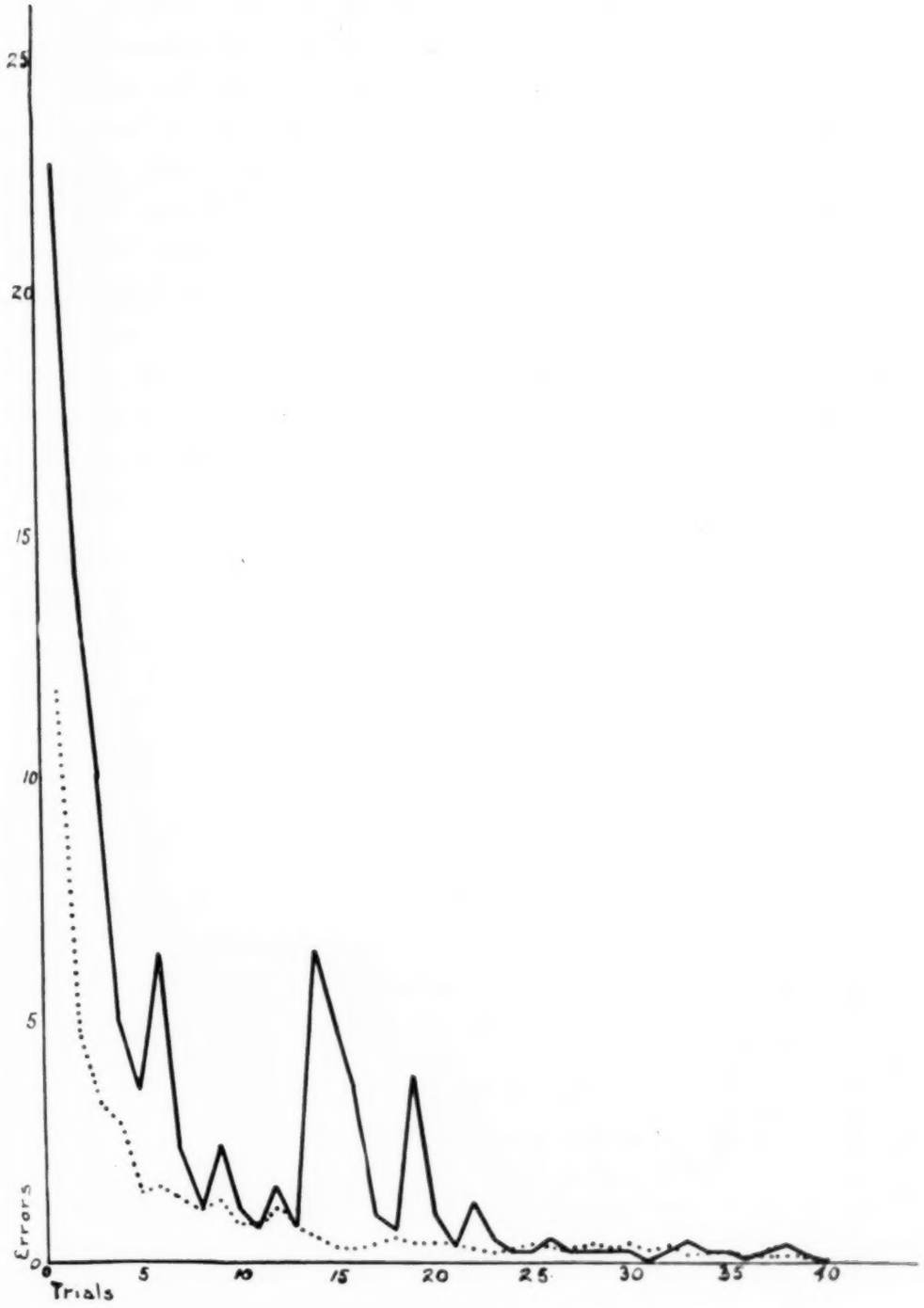


FIG. 2. Curves showing the average number of errors made in the maze problem by the normal and blind groups in each of the first forty trials. The straight-line curve is that of the blind group; the dotted, that of the normal group.

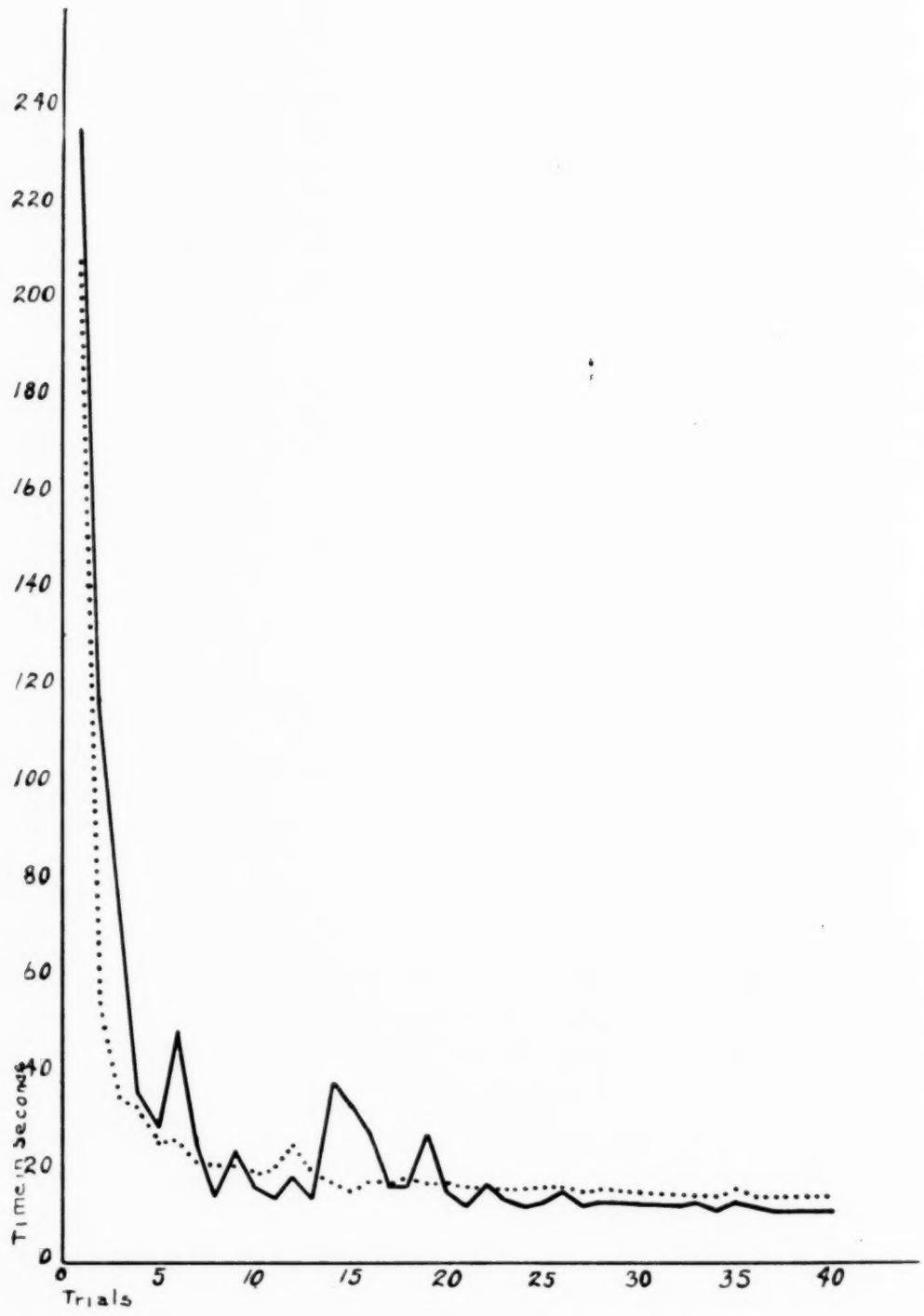


FIG. 3. Curves showing the average number of seconds spent on the maze problem by the normal and blind groups in each of the first forty trials. The straight-line curve is that of the blind group; the dotted, that of the normal group.

The error and time curves (see Figs. 2 and 3) show the learning of the normal group to proceed both more readily and more regularly than that of the blind group. (The curves of the blind group have many more steeples.) The progress of the blind from trial to trial, furthermore, is not only less consistent than that of the normal but the measures of variability (see Tables III. and IV.) indicate that the blind as a group of individuals are also more variable than are the normal subjects.

A separate consideration of the performances of those who have been blind from birth and of those who have had some sight reveals the degree of maze success to be paralleled negatively by the amount of visual deprivation of the subject. (See Table V.) In accordance with this tendency are also

TABLE V

AVERAGE AGE, INTELLIGENCE-TEST SCORE, AND MEASURES OF MAZE PERFORMANCE. NORMAL SUBJECTS, SUBJECTS TOTALLY BLIND FROM BIRTH AND SUBJECTS BLIND OR PARTIALLY BLIND, BUT NOT FROM BIRTH

Group	Age	Intelligence-Test Score	Trials (Maze)	Errors (Maze)	Time (Sec.) (Maze)
Blind from birth	18.8	91.6	37.7	232.2	1461.2
Blind, but not from birth	18.2	85.1	17.2	71.3	670.0
Normal vision	18.3	90.4	16.8	41.4	583.2

the negative correlations between the years of visual experience of the blind and the measures of the difficulty experienced in learning the maze. (See Table VI.) These correlations,

TABLE VI

CORRELATION OF YEARS OF VISUAL EXPERIENCE WITH AGE, INTELLIGENCE-TEST SCORE, AND MEASURES OF MAZE PERFORMANCE. BLIND GROUP

	Age	Intelligence-Test Score	Trials (Maze)	Errors (Maze)	Time (Maze)
Years of Visual Experience	$-.06\pm.15$	$+.02\pm.15$	$-.15\pm.15$	$-.19\pm.15$	$-.13\pm.15$

to be sure, are small and, hence, their significance is questionable. Still, since the type of visual experience varied—some subjects had many years of shadow vision, while others had a

TABLE VII

AGE, INTELLIGENCE-TEST SCORE, AND MEASURES OF MAZE PERFORMANCE. FIVE SUBJECTS FROM EACH OF THREE VISUAL GROUPS MATCHED APPROXIMATELY ON THE BASIS OF AGE AND INTELLIGENCE-TEST SCORE

Normal Vision						Blind, but not from Birth						Blind from Birth					
Subject	Age	Intell'ce-Test Score	Trials (Maze)	Errors (Maze)	Time (Sec.) (Maze)	Subject	Age	Intell'ce-Test Score	Trials (Maze)	Errors (Maze)	Time (Sec.) (Maze)	Subject	Age	Intell'ce-Test Score	Trials (Maze)	Errors (Maze)	Time (Sec.) (Maze)
8N	17	56	20	66	1487	1PB	16	65	9	33	341	1B	20	67	27	86	1055
2N	20	75	9	57	525	7PB	20	79	20	32	460	2B	20	72	142	1056	5977
16N	21	97	3	14	231	4PB	21	97	7	59	550	3B	21	98	15	52	359
5N	17	104	10	9	189	3PB	16	98	8	85	1267	4B	16	104	20	53	443
6N	15	118	8	18	450	6PB	18	115	15	24	120	5B	16	117	9	25	205
Mean	18.0	90.0	10.0	32.8	576.4		18.2	90.8	11.8	46.6	547.6		18.6	91.3	42.6	254.4	1607.8

few years of excellent vision—and the mere measure 'years of experience' does not take these differences into account, one would anticipate small correlations.

If we attempt, as a further check, to control in an absolute way, in so far as it is possible to do this with a few cases, the factors of age and intelligence by selecting for comparison from the three visual groups only those subjects highly similar in these respects (see Table VII.), we observe that the same negative relation obtains between the ease with which the maze is mastered and the degree of visual deficiency. A limited amount of vision, however, seems to be fairly effective in reducing the handicap of the blind; for those who have seen at some time in their lives maintain a standard more nearly similar to that of the normal subjects than they do to that of the totally blind. These results, again, support our earlier observations, though the magnitude of the differences between normal and blind subjects is not so great as was indicated in the later findings. We must insist, furthermore, that our comments on the abilities of the blind subjects apply merely to the average. Some of those whose optic apparatus has never functioned attained a much higher degree of success with the maze than did many of those with normal visual powers.

An interpretation of our results in the light of Warden's data seems possible. Warden demonstrated that of the three principal ways of guiding one's conduct in the maze—namely, by giving oneself verbal directions, by building up a visual schema, or by relying upon kinæsthetic and tactual cues—the first is the most effective; the last the least. Those whose visual deprivations have been of life-long duration would necessarily fail to employ the second method, and those whose affliction has been of shorter duration probably would not use the visual schema so much, at least, as would the normal subjects. The blind, then, would rely largely, no doubt, on the first and last techniques suggested; but, since the tactual-kinæsthetic-motor adjustments, which are necessarily the principal bases of the spatial reactions of the blind, are probably not so easily discriminated, (or, as the *Gestalt* psy-

chologist would have it, do not develop so clear a configuration), and hence are not so readily named, as they are when a visual factor is added, we should expect the totally blind, at least, to learn the maze with relatively little verbalizing. Logically, then, the amount of verbalization of a directive sort engaged in should parallel, on the average, the amount of visual experience of the subjects. An entirely satisfactory check on this hypothesis we were unable to obtain because of the general immaturity of our subjects and their unfamiliarity with the technique of self-observation. Notations, however, were made on the conduct of the subject during the learning period. These, crude as they are, do lend the hypothesis some support, for the three individuals, 11PB, 5PB, and 3PB, who gave themselves audible directions to any extent were all among those whose affliction was of rather late origin or whose sight was never entirely destroyed. Their visual experience has extended, respectively, over 17, 12, and 14 years.

Our results we tested, furthermore, by one of Warden's criteria of directive verbalization: namely, the degree of variation in the difficulty of the cul-de-sacs as measured by the average number of entrances. (See Table VIII.) He con-

TABLE VIII

RELATIVE DIFFICULTY OF THE CUL-DE-SACS. ALL GROUPS. BASED UPON A "DIFFICULTY" VALUE = 1.0 GIVEN TO THAT CUL-DE-SAC ENTERED (ON THE AVERAGE) BY EACH GROUP THE LEAST NUMBER OF TIMES

Group	Cul-de-sacs						
	I.	II.	III.	IV.	V.	VI.	VII.
Normal vision	3.44	1.04	1.62	2.92	1.76	5.00	1.00
Blind from birth	5.90	4.01	4.29	6.05	1.00	4.00	2.72
Blind, but not from birth	3.73	1.88	2.21	3.53	1.92	3.96	1.00
Blind group (total)	3.29	2.21	2.90	3.27	1.00	2.72	1.29

tends that the variation is least in the case of those who depend largely on the word control and most in the case of the motor learners, the visualizers occupying an intermediate position. While those of our subjects who have never seen do show to a somewhat more marked degree than do the normals the aforesaid variation, the same condition does not obtain for

those whose visual deprivations are distinctly post-natal. These results, then, are indecisive. A detailed analysis of the cues which the blind do use is a problem still in need of attention and certainly one of no small size. The significance of the problem for the pedagogics of the visually handicapped needs no comment.

Summary

1. Blind subjects tend to be less successful, on the average, in maze-learning of the stylus variety than are normal subjects. The error criterion of skill in maze performance differentiates the two visual groups more markedly than does either the trial or time criterion.

2. Some visual experience before the onset of blindness seems to reduce materially the handicap which the blind as a group appear to suffer.

3. The intelligence of the subject, whether he is with or without defective vision, determines, in part, the ease with which he masters the maze.

THE VISUAL ESTIMATION OF ANGLES

BY MARJORY BATES PRATT

For many years it has been assumed, though not always without question, that acute angles are overestimated, and that obtuse angles are underestimated. This supposition seems not to have been considered interesting in itself, but valuable only as it was related to the study of certain geometrical optical illusions. The assumption as to the overestimation of acute angles, and to a lesser degree the underestimation of obtuse angles, appears to have sprung directly from the study of such illusions, and to have been made in order to provide an explanation for these more complex phenomena.

Hering [1] says that angles less than 60° are overestimated and those greater than 60° are underestimated, on the ground that the Poggendorff illusion disappears at 60°. Elsewhere 90° has been taken as the dividing line in wrong estimation of angles.

Brentano [2] is the first to explain the Müller-Lyer illusion on the basis of overestimation of acute and underestimation of obtuse angles.

Helmholtz [3] remarks, in attempting to account for the Poggendorff illusion, that acute angles seem larger than they really are when they are observed together with obtuse angles.

Wundt [4] regards the overestimation of the acute angle when compared with the obtuse as involving the same principle as that of filled space. In the case of the acute angle the free movement of the eye is inhibited and the angle seems larger because more work has been required in observing it.

Judd [5] speaks of the 'fact' that acute angles are overestimated and obtuse angles underestimated, although he holds that the length of the lines is the important condition in geometrical optical illusions and he considers the wrong estimation of angles as merely a secondary effect.

Pierce [6] tried adjustments of the Poggendorff illusion by the method of average

[1] E. Hering, *Beitr. z. Physiol.*, 1861, 65 ff.

[2] F. Brentano, Ueber ein optisches Paradoxon, *Zsch. f. Psychol.*, 1892, *3*, 349 ff.

[3] H. Helmholtz, *Handbuch der physiol. Optik*, 1896, *2*, 708 ff.

[4] W. Wundt, *Grundzüge der physiologischen Psychologie*, 1893, *1*, 142 ff.

[5] C. H. Judd, A study of geometrical illusions, *Psychol. Rev.*, 1899, *6*, 241 ff.

[6] A. H. Pierce, *Studies in auditory and visual space perception*, 1901, 271 ff.

error and found evidence that the acute angles involved were misjudged, but in opposite directions, the upper usually being overestimated and the lower underestimated.

The results of Pierce are probably responsible in part for the attitude of Ladd and Woodworth [7] who remark that it is "doubtful whether the overestimation of acute angles is, in reality, a universal principle which can be freely invoked for the explanation of these illusions."

Since nothing had thus far been done to test experimentally the estimation of angles in their own right, the present study was undertaken with the purpose of discovering whether with one angle alone wrong estimation would occur in the manner which had been supposed.

In order to simplify this account we speak of wrong estimation when we mean either overestimation or underestimation, the 'wrong' signifying 'not in accord with a certain physical standard.' Now wrong estimation may be studied either by asking O to set, for example, an angle of 45°, or by presenting some angle and asking him to compare it with his notion of an angle of 45°. In other words a comparison is made, not between two stimuli, but between a physical standard, and a mental standard, the outward and visible sign of which is either the angle which O has set or the judgment 'greater,' 'equal,' or 'less.' In the case of O's setting an angle, E does the actual comparing, *i.e.*, between a physical standard and the evidence of O's mental standard; but, in the other case, O makes the comparison, *i.e.*, as between a physical object and a mental standard. (Whether or not O makes comparisons between physical stimuli and a mental standard in the form of an image when he sets an angle is beside the point here since E makes the only comparisons which have statistical value.)

With these facts in mind let us define what is meant by overestimation and underestimation. Overestimation takes place, in the case of O's setting the angle, when the physical standard is greater than O's mental standard. If an angle of 45° is asked for and O sets one of 44° this means that O has given the value of 45° to something that is really only 44°;—that is to say, he has overestimated the size of the physical angle of 44°. It would seem at first glance that overesti-

[7] G. T. Ladd & R. S. Woodworth, *Elements of physiological psychology*, 1911, 445.

mation must take place when the mental standard is greater than the physical. But it is with overestimation of physical objects that we are concerned, and physical objects seem too large only when compared with a mental standard which is too small. A child of five seems 'tall for his age' only when our conception of a child of five is of one considerably shorter.

In the case also where O makes a judgment as to whether a given angle is greater, equal or less, as compared with his conception of an angle of a certain number of degrees, overestimation takes place if the physical standard is greater than O's mental standard, as evidenced by O's generally rating the physical stimulus greater than it really is. If an angle of 45° is presented and O says 'greater (than 45°),' that means that O's mental standard is less than the physical, and that if he had been setting an angle of 45° he would presumably have made it too small. Exactly the opposite of the above is true, of course, of underestimation.

Preliminary Series

The first series of experiments was done at Ohio State University during the academic year 1922–1923. The work was interrupted before it was completed, hence the results can be considered of value only as they are related to those of the main series. The method of constant stimuli was used; a Whipple tachistoscope placed in a dark room giving brief exposures of black angles drawn on white cardboard backgrounds. These angles had arms 2 mm in width and 4.5 cm in length. They all faced towards the right (vertex pointing towards the left) with the horizontal arm as the base.

The three Os were all undergraduate students in elementary psychology. Instructions were simply to judge whether the angle presented was greater or less than, or equal to an angle of 45° or of 135°, as the case might be. These angles were chosen partly because they are typical of an acute and an obtuse angle respectively, but chiefly because they are the only angles (except, of course, that of 90°) of which the average O has any clear conception.

At the end of the series, generalized reports were obtained from observers D and C.

The following table gives the main numerical results.

TABLE *A*

IN THE TOP LINE *C* = crude error and N = number of judgments.

Obs.	N	45°	C	N	135°	C
C.....	100	45.50	0.50			
B.....	100	38.25	6.75			
D.....	100	44.45	0.25	30	137.75	2.75

It will be seen that, with 45°, there is hardly any wrong estimation in the cases of OC and OD. The only O who definitely estimates 45° wrongly is OB whose mental standard is 6.75° too low. That is to say, she overestimates by 6.75°. OB is the only O, then, who does what might have been expected. The others are simply neutral. As for OD in the case of 135°, she underestimates by 2.75°. The fact, however, that this figure is based on only 30 cases limits its significance.

PRINCIPAL SERIES

The second series was done at the Psychological Laboratory of Harvard University during the summer of 1924. The six Os were summer school students in general psychology, except for OP and OR who were members of the department.

The method of average error was used. The apparatus used consisted of an upright background on which was an angle, one arm of which was movable. The background was of white cardboard and was circular (50 cm in diameter) except where it fitted into a black grooved board (40 cm × 10 cm) at a point 15 cm below the center.

The circularity was intended to eliminate any comparison O might be tempted to make between the direction of the angle and the edge of a rectangular background. A black line 16 cm long and slightly less than 1 cm wide was painted with one end beginning at the center of the background and stretching horizontally to the right. The movable arm was a piece of brass, painted black, also slightly less than 1 cm wide and 16 cm long. It was attached by a pin which projected through the cardboard from the center of a small wheel mounted on a standard. Firmly attached at one point to the grooved edges of this wheel was a narrow rope each end of which emerged through the black board and ended on a table in front of O, 3.30 meters away. By pulling either end of the rope O could control the direction of movement of the brass arm. Moving with this arm was a pointer by means of which E could read off on the reverse side of the background the exact setting in degrees.

Fairly dull daylight illumination was used. Shades were always raised and lowered in such a way that no perceptible shadow was cast by the movable arm, which of necessity was separated slightly from the background.

The instructions were as follows:

"After the signal 'Ready' you are to pull the right-hand (or left-hand, according to the position of the movable arm) string until you have made what appears to you to be an angle of 45° (or 135°). Pull in only one direction. If you go too far tell E and the experiment will be repeated."

The latter part of the instruction had for its purpose the control of any influence due to the direction from which the critical point was approached. On presentation to O the movable arm was sometimes at 0° and sometimes at 180°. These two positions alone were used in order to give the effect merely of a straight line, since the presenting of various angles might have been somewhat confusing to an O who was trying to pay attention to his own notion of the angle which he was required to set. The movable arm was never in a position below the horizontal stationary arm, hence all adjustments were made within the upper 180° of the circle of which the two arms were radii. After every 20th judgment a generalized report was asked for until the judgments became so automatic that O had nothing further to say.

TABLE I

RELATIVE AMOUNTS OF OVERESTIMATION (o) AND UNDERESTIMATION (u)

N = number of judgments; MV = variation, and C = crude error. Column d gives the initial position of the moving arm.

Obs.	N	d	Ser. A (45°)	MV	C		N	d	Ser. B (135°)	MV	C	
					o	u					o	u
P	200	180	44.02	2.74	0.98		50	180	135.40	1.07		0.40
	25	0	44.78	0.51	0.22		200	0	134.15	2.50	0.85	
R	50	180	42.65	1.93	2.35		50	180	128.98	3.06	6.02	
	50	0	41.51	1.98	3.49		200	0	127.46	2.69	7.53	
F	100	180	46.67	1.56		1.67	100	180	136.61	1.60		1.61
	50	0	46.51	1.37		1.51	50	0	136.92	1.37		1.92
Y	100	180	45.42	2.37		0.42	100	180	140.25	3.30		5.25
	50	0	49.48	1.98		4.48	50	0	138.81	2.36		3.81
H	100	180	40.72	1.49	4.28		100	180	129.49	2.34	5.51	
K							100	180	138.95	5.26		3.95
Averages				1.78	2.26	2.02				2.55	4.98	2.82
Differences					0.24						2.16	
Average undifferentiated crude error					2.15						4.11	

It is clear from Table I. that wrong estimation occurs in both directions with the typical acute angle of 45°, and also with the typical obtuse angle of 135°. Three Os overestimate the angle of 45°; two underestimate it. Two Os overestimate the angle of 135°; two Os underestimate it. OP does both, since the original position of the movable arm changes the direction of his error. As for the average amount of wrong estimation in both cases, overestimation prevails very slightly, though much less in Series A than in Series B. By averaging the total crude errors in each direction and finding the difference between these averages, we come out with 0.24 for Series A and 2.16 for Series B, neither of which values can be considered significant. Disregarding the direction of the wrong estimation, the average crude errors of Series A and Series B are 2.15 and 4.11 respectively; *i.e.*, the crude error in setting the angle 45° is only a little more than half as great as that in setting the angle 135°. Almost the same relationship holds for the average mean variation, which is 1.78 for Series A and 2.55 for Series B.

In Table II. the influence of the setting can be seen. It appears that for 45° a setting at 0° tends to give underestimation, and a setting at 180° to give overestimation, and that for 135° exactly the reverse happens. The differences, however, are too slight to be considered significant.[8]

TABLE II

SHOWING THE INFLUENCE OF THE ORIGINAL POSITION OF THE MOVABLE ARM

Obs.	Series A		Series B	
	0°	180°	0°	180°
P	44.78	44.02	134.15	135.40
R	41.51	43.65	127.46	128.98
F	46.51	46.67	136.92	136.61
H		(40.72)		(129.49)
Y	49.48	45.42	138.81	140.25
K				(138.95)
Averages	45.57	44.89	134.33	137.08
Differences	0.68		2.75	

[8] In calculating the significances of these differences we find that the highest value for P_z is only 0.6445. The values are, for Table I, Series A, 0.1286, Series B, 0.6445; Table II, Series A, 0.2994, Series B, 0.6339.

In comparing the results of the principal and the preliminary series (the one carried through under the method of average error and the other under the method of constant stimuli) it will be found that the results do not contradict each other. That is all that can be said, if we take OB as somewhat atypical and if we disregard OD's meagre results with the angle of 135°.

Let us proceed, then, to examine, quite by themselves, the results of the principal series. In the first place, Table I. shows that acute angles are no more apt to be overestimated than to be underestimated, and that the same thing may also be said of obtuse angles; in other words, overestimation and underestimation cancel each other. With regard to the relationship of these results to the problem of certain illusions and their explanation in terms of wrong estimation of angles, we can only say that our results taken as a whole give such an explanation no support. Even by taking individual cases there is at least no correlation between overestimation of acute and underestimation of obtuse angles. Except in the case of OP with the original position of the moving arm at 180°, those who overestimate 45° also overestimate 135°, as it is also true that those who underestimate 135° also underestimate 45°.

The relatively high crude errors and mean variations in the case of the estimation of 135° probably mean, respectively, that the Os were less familiar with the 135°-angle and were therefore less able to estimate it accurately than the 45°-angle; and (again owing to their relative uncertainty about the angle of 135°) that their mental standards for it varied more widely than for the angle of 45°.

In considering again Table II., we see that the setting makes only an insignificant difference, and we can therefore be fairly sure that kinæsthetic cues connected with pulling the strings had little to do with the judgment.

The Observers' Reports

The meager reports obtained in the first series need not be discussed, since they showed no element which was not also

found in the main series, even though the main series was done by a different method.

Perhaps the most important point to be considered here is that the Os quite naturally and without instruction regarded the 45°-angle and also the 135°-angle in their relation to either 90° or 180°. The 45°-angle, for example, was taken at least part of the time by every O as half a right angle and the angle was then judged on the basis of whether the varying arm did or did not bisect this imagined right angle. In other words these angles in most cases had no existence in their own right. The tendency seemed not to judge the area bounded by the arms of the angle, but rather to judge this area only secondarily and to base the real judgment on the relative position of the arms. This tendency is only natural, perhaps, since the arms are two very definite lines, whereas the area which they bound on two sides could be definite only if a third line were imagined joining the ends of the arms.

The ways of regarding the two arms varied a little from one O to another. With OP the bisection was imagined as made by the diagonal of the square which could be erected with the horizontal arm of the angle as its base. This method was also used somewhat by OR, OF, and, occasionally, by OY. Both OR and OY also thought of the varying arm as bisecting a sector of a circle, part of the circumference of which was formed by the circular edge of the background. OH apparently used this method almost exclusively.

OP and OY both narrowed their fields of vision to only a very small area near the vertex of the angle in judging whether or not a bisection was being made. OP observed that his judgments were apt to change considerably if his field of vision suddenly widened.

OP and OR found that there was a fairly large range over which the angle looked to be either 45° or 135°. It was only by assuming a very critical attitude that they could say that one position of the moving arm seemed better than another.

It is interesting to note that OH offered the comment that the angle of 45° had always, in his every-day experience, looked larger than it really was, and that the results squared

with this observation by showing in his case a quite decided overestimation.

Summary of Results

1. In the present experiment both acute angles and obtuse angles (45° and 135° were taken to be typical) were as apt to be overestimated as they were to be underestimated. There was a tendency towards overestimation in both cases, but this tendency was found to be numerically insignificant.

2. The tendency towards overestimation was not uniform. Approximately half the Os overestimated the angle of 45°, and half underestimated it. The same was true of the angle of 135°.

3. As a general rule those Os who overestimated acute angles also overestimated obtuse angles, and those who underestimated acute angles also underestimated obtuse angles. There was only one slight exception to this rule.

4. Judgments of acute angles were more uniformly accurate and consistent than those of obtuse angles.

5. According to the observers' reports the size of an angle was usually judged not by directly estimating the amount of space between the two arms but rather by judging the position of these arms with respect to certain imaginary lines. By means of this judgment the size of the angle was inferred.

AN APPARATUS FOR MEASURING REACTION TIMES WITHOUT A CHRONOSCOPE

BY DAVID WECHSLER

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This paper describes an apparatus, originally devised to measure alertness of attention and speed of reaction, which promises to be useful in the general field of experimental psychology. The apparatus consists of two units. The first enables the experimenter automatically to present several stimuli, simultaneously, successively, or both together and in sequence; the second automatically records the subject's responses as they are made. The two units may be used together or separately. When used together they furnish a means of measuring reaction-time without the use of a chronoscope.

Automatic Presentation of Multiple Stimuli

Figure 1 shows the construction of the first unit. A metal cylinder (*CL*) is connected to an electric motor (*M*) which moves the cylinder at a very low speed by a series of reduction gears. The cylinder is covered with an insulating sleeve (*SL*). From this sleeve are cut out, at varying intervals and of different dimensions, windows which expose small portions of the metal. Over the cylinder are placed a number of metal fingers, f_1, f_2, f_3, which make contact with the cylinder whenever one of the windows passes beneath. The fingers complete one or another of several circuits, such as f_1–S_1–Mg_1–A or f_2–S_2–Mg_2–A. S_1, S_2, S_3 are excitatory mechanisms; Mg_1, Mg_2, Mg_3 are electromagnets. Both are connected in simple series with the metal fingers. The function of each of the excitatory mechanisms is to produce a particular stimulus. The electromagnets function in connection with the second or recording unit of the apparatus.

From the arrangement of the parts and the electrical con-

nections indicated in Fig. 1, it is obvious that every time one of the fingers makes contact with the metal cylinder a par-

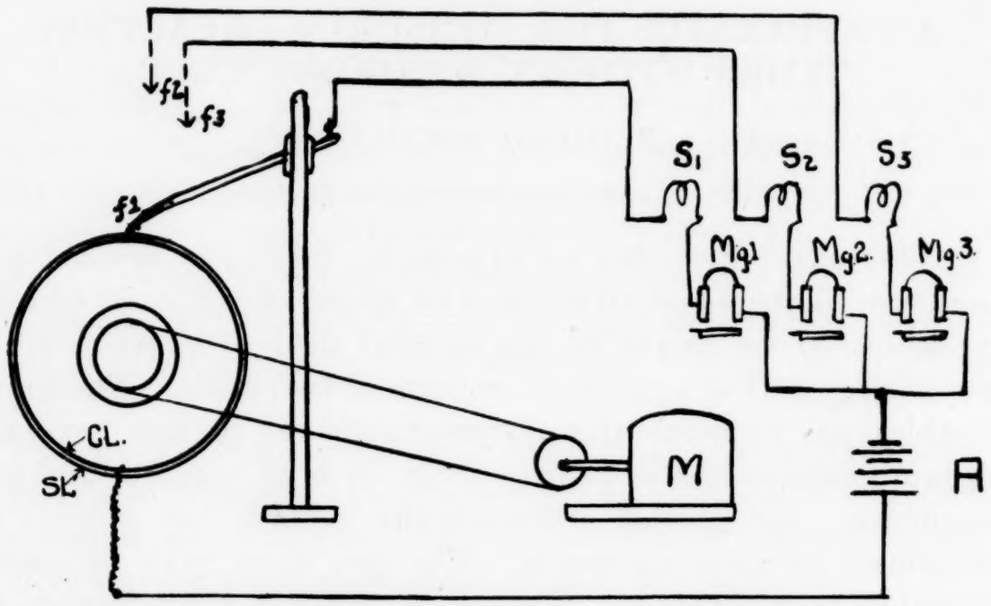

FIG. 1

ticular stimulus is set off and continued so long as the contact is maintained. The duration of a stimulus will depend upon the speed at which the motor is revolving and the dimension of the window; the frequency with which it appears, upon the number of times a like window passes under its corresponding metal finger. All these factors may, of course, be determined in advance by the experimenter, who can thus control the frequency and the order of his stimuli as well as their duration. Moreover the number of different *kinds* of stimulus that can be employed simultaneously is only limited by the width of the cylinder.

RECORDING THE RESPONSES

The mechanism of the second unit of the apparatus (Fig. 2) enables the experimenter to obtain an automatic record of the reactions to a series of stimuli. Connected in series with the source of current (25 volts) are several make-and-break mechanisms (R_1, R_2, R_3), *e.g.*, push buttons or telegraphers keys, certain of which the subject uses in response to the various stimuli, and likewise a number of electric counters

(C_1, C_2, C_3) which will register these responses when the individual circuits of which they form part are entirely closed or completed. But each of these circuits can be completed only if already partially closed at the points p_1, p_2, p_3, which are controlled by the electromagnets Mg_1, Mg_2, Mg_3 in series with the stimulus-provoking mechanisms shown in Fig. 1. Thus, when the stimulus S_1 is presented, the current flowing through the circuit f_1–S_1–Mg_1–A (Fig. 1) causes the armature, a_1, to be attracted to the metal block, b_1, thereby closing the circuit a_1–b_1–p_1–R_1–B (Fig. 2) at point p_1. But the circuit is still

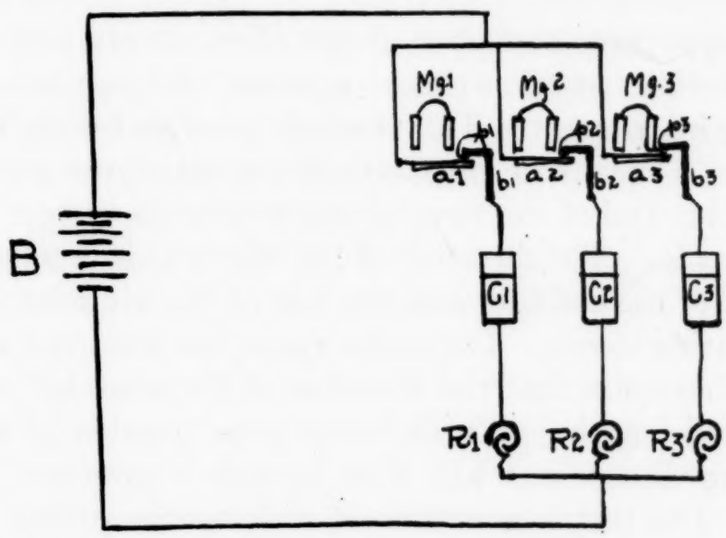

FIG. 2

open at point R_1 and can be completed only when the subject makes contact at this point by reacting with the appropriate response. Hence, if R_1 is the correct response to S_1, the circuit can be completed only when the subject reacts with R_1. If he accomplishes this within the time that the stimulus is being maintained, the response will be recorded by the counter. C_1; if he responds too late, or with any other reaction, such as R_2 or R_3, the circuit cannot be completed and the counter C_1 will fail to register. Nor will any of the other counters (*e.g.*, C_2 or C_3) register, since the circuits of which they form part are open at the points p_2 and p_3 respectively.

The automatical record of responses to various forms of stimulus is made possible, as indicated above, by the use of elec-

tric counters which both record and total the subject's reactions as they are made. The only task left to the experimenter is to note the counter-readings at the beginning and at the end of the experiment. The difference between the two figures is the number of correct reactions made within the permitted time. Errors or wrong reactions could also be recorded by the use of additional counters and by certain modifications in the electric circuits. For the sake of simplicity these have not been considered.

Measuring Reaction Time without a Chronoscope

The apparatus described above offers a very easy method of calculating reaction-times without the use of a time-recording instrument. This is made possible by the fact that it supplies a means of automatical control of the duration of the stimulus and of the time within which the correct reaction may be made. The duration of the stimulus is determined by the speed of the cylinder and the size of the windows cut from the insulating sleeve. Given the speed the windows are made of such dimension that the duration of the stimulus will be of any desired length. A sufficiently large number of windows of varying dimensions will then furnish a graded [1] series of stimuli. The rest is a matter of making the proper connections between Unit 1 and Unit 2 of the apparatus. All stimuli of a given duration are connected with a particular electric counter which then registers the total number of correct reactions for this time; that is to say, the total number of successes for a particular reaction-time interval. From the figures thus obtained it is then easy to calculate a subject's mean reaction-time in a manner similar to that employed in calculating a limen by the method of right-and-wrong cases.[2]

An illustration will make the method clear. Suppose that we desire to calculate the motor reaction-time to a visual stimulus. We decide first on the limits of our durations.

[1] The durations of the stimuli, should, when possible, vary by some constant interval. This simplifies the calculations.

[2] In our experiment a successful reaction would correspond to a correct (right) judgment, a failure to react within the time interval to an incorrect (wrong) judgment. No distinction is made between a failure to react and an incorrect reaction.

For practical purposes 100 to 300 sigma are convenient limits. We next select the constant interval by which our reaction times are to differ. Suppose that it is 25 sigma. Then we cut windows in the insulating sleeve of such dimensions that the metal fingers will form contact with the cylinder for periods of 100, 125 . . . 300 sigma.[3] A sufficiently large number of windows are cut out to present each stimulus at least 10 times during the course of the experiment. This furnishes us with a graded series of stimuli of durations differing by a constant interval. Our apparatus enables us to record separately the successful reactions to each of these stimuli. This is done by the electric counters. All that we require at the end of the experiment is, then, to read off the totals from each of the counters and to tabulate them in an ascending or descending series thus:

Duration of Stimulus	Per cent. of Correct Reactions [4]
100 Sigma	0
125 "	10
150 "	25
175 "	45
200 "	70
225 "	85
250 "	95
275 "	98
300 "	100

It is then a matter of simple arithmetic to calculate the mean reaction-time or other desired value by means of available psychophysical formulas.

[3] Allowance must be made for the 'lags' in the various parts of the apparatus, and the dimensions of the windows corrected accordingly.

[4] The figures are hypothetical.

A SPECTRUM COLOR-MIXER

BY C. E. FERREE AND GERTRUDE RAND

Bryn Mawr College

In the research work of our laboratory we have long felt the need of reducing color-mixing to a quantitative basis. By means of apparatus which provides a physical measure of the stimulus and of methods which permit a numerical comparison of responses to the stimuli employed, it has been possible to make in several fields a quantitative determination of selectiveness of response;—to find out in an exact and definite way just what are the peculiarities of the visual responses as compared with each other and with other types of response to light-energy. The present apparatus was designed primarily that this type of investigation might be extended from the simple sensory and 'acuity' functions to the more complex function by which colors are combined. In view of a limited budget there has been need also to devise a plan sufficiently simple to fall within the mechanical capabilities of an instrument-maker of the college type and one that would not tie up too much money and equipment in a single fixed instrument serving only a limited purpose.

The apparatus to be described is in the form of a comparatively simple attachment which can be used in connection with a spectroscope of the usual type. By means of it the following combinations may be made: (*a*) Wave-lengths from any two parts of the spectrum with a range varying from identity to the widest possible difference. (*b*) Wave-lengths from three parts of the spectrum with a considerable range of choice in the colors selected. (*c*) Wave-lengths from four parts of the spectrum also with a considerable range of choice in the colors selected. (*d*) A pair of complementary colors with any other color in the spectrum, of use perhaps in colorimetry by the monochromatic method to furnish a variable achromatic component to be combined with the standard

color. In such a case not only the standard color can be specified in terms of energy, but also the achromatic component with which it is combined. And (*e*) a pair of complementary colors with a mixture of two other colors in varying amounts with a considerable range of selection of the colors forming the mixture; a combination serviceable in colorimetry by the two-color method. Here both the mixture used as the standard color and the variable achromatic component may be specified in terms of energy. In case, however, the instrument is used in colorimetry by the three- or the four-color methods the achromatic component, if needed, will have to be supplied in the usual way by white light reflected into the system from the surface of the prism of the spectroscope.

The device consists of two parts: the objective slits, with the mechanism for their control and adjustment, and the optical system.

The Objective Slits:—The slits with the mechanism for their control and adjustment are shown in Fig. 1. The slits S (Fig. 1*A*) are four in number of fixed breadth, $\frac{1}{2}$ mm., and of variable height. Suitably spaced, they are cut in two plates P_1 each of which, driven by a screw Sc_1, may be made to travel transversely across the spectrum, one above the other. These plates, with their slits, serve to divide the spectrum horizontally into two equal parts. The plates are supplied with guides so placed that the lower edge of one plate is contiguous with the upper edge of the other, the joint being made light-tight by a slight right-angled overlap O_1 (Fig. 1*B*) $\frac{1}{2}$ mm in breadth, cut into the opposite faces of the two plates. Two of the slits are cut in the upper plate and two in the lower. Each pair of slits may be made to travel from one end of the spectrum to the other in a fixed relation by means of the screw Sc_1 which moves the plate in which they are cut. Also the difference in distance between the slits may be made to vary over a considerable range. This is accomplished by making each of the plates in two parts, joined by a right-angled overlap O_2 (Fig. 1*C*) cut into the opposite faces of the two halves of the plate. The difference in the distance between the two slits can thus be made to vary

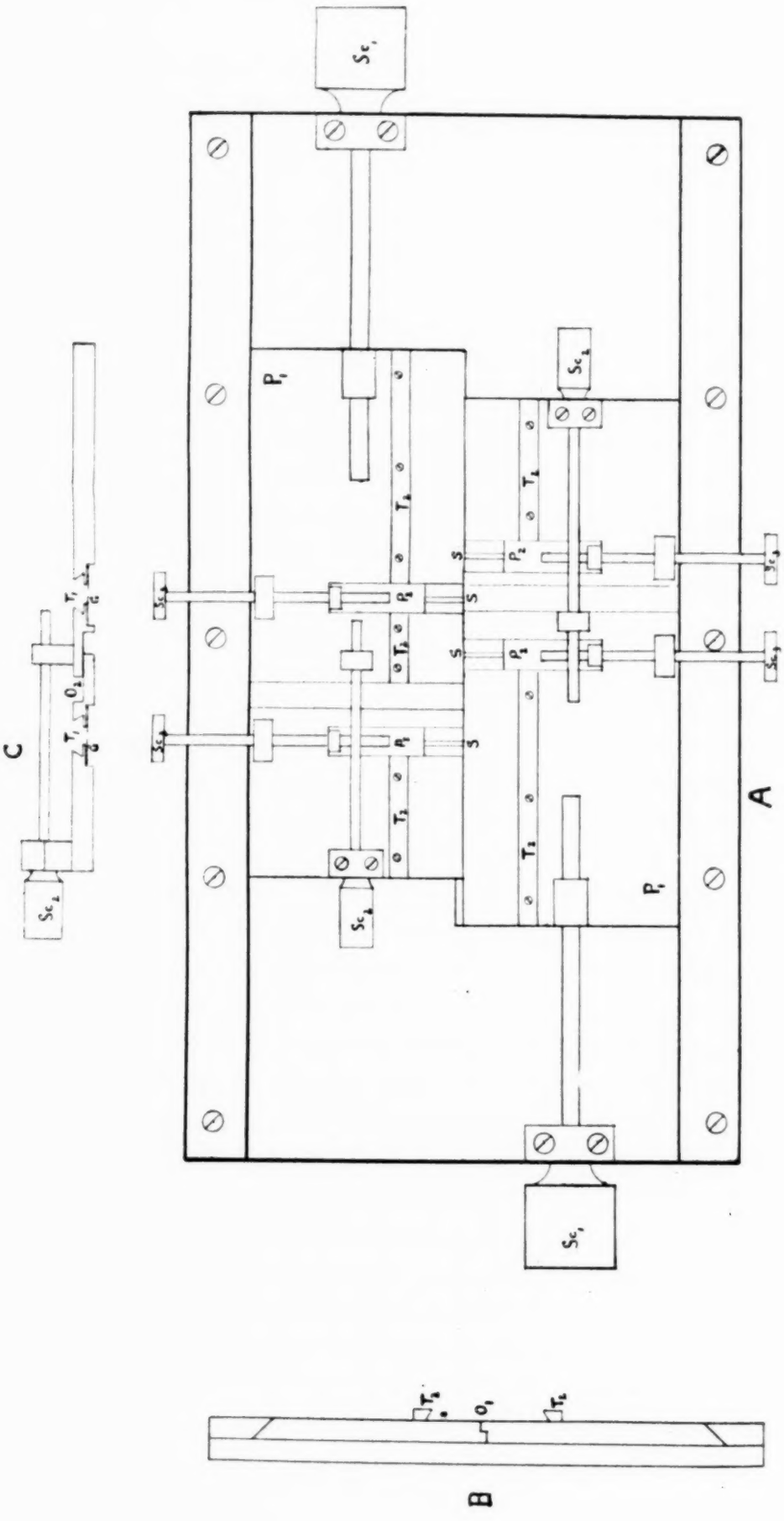

FIG. 1. Objective slits

by the length of the overlap. The slits are moved through this range of adjustment by a screw Sc_2 one support for which is on one half of the plate, the other on the other half. Thus one of the slits may be placed in any part of the spectrum by turning the screw which moves the whole plate, and the distance of the other slit from that one may be varied by turning the screw which controls the adjustment provided by the overlap. Each of the two plates is provided with this means of moving one of the slits to any part of the spectrum and varying the distance of the other slit from the one so placed or located. If in the use of the instrument in connection with any particular problem a wider range of variability of distance between the two slits is wanted for one or both of the plates, this may be secured by using plates with a longer overlap. There are limitations, of course, to the use of an overlap for producing a variable distance between the slits. Different lengths of overlap, however, may be used for different purposes as the need arises. It would seem that most of the needs of three- or four-color mixing could be satisfied with a single overlap. In two-color mixing two of the slits are closed completely by a device to be described later, leaving one open slit in the upper and one in the lower plate. By means of the screws which move the two plates, the relation of the two slits can be made to vary from vertical continuity to the widest possible separation in the spectrum.

In order to be able to close entirely any one of the slits or to vary in continuous series the amount of light coming through, a thin narrow plate P_2 (Fig. 1*A*) is made to travel over it, from top to bottom, by means of a screw Sc_3, the supports of which are mounted on the plate containing the slit and travel with the slit. These control plates move in a grooved track T_1 (Fig. 1*C*) cut in the plate containing the slit. At the bottom of this track, at which place the plate is very thin, is cut the slit. Thus the desired thinness of edge is secured. An excellent slit may be obtained by cutting a wide opening in the bottom of the track and fastening to the back of the plate, in a suitable shallow insert, segments of a Gillette razor blade *G* (Fig. 1*C*) with the desired degree of separation

between the two edges. This method of securing a satisfactory slit has frequently been used by us. By means of these control plates the amount of any of the component lights used in the mixture may be varied from full intensity to total extinction.

Above and below the slits running in a transverse direction are two grooved pieces to form a track T_2 (Fig. 1*A* and 1*B*) by means of which the thermopile needed to make the energy measurements is moved into place from either side. This track is fastened to the plate containing the four slits, and is made in sections to permit freedom of motion of the two halves of each plate. In measuring the energy of light one of the lower slits may be made continuous with one of the upper, if need be, thus utilizing the full intensity of the beam at that point.

The Optical System.—It has been our intention to provide two types of optical system, one designed to mix the colored lights on some diffusely reflecting surface, the other to focus the mixed beam on the eye. The latter of these, however, has not as yet been satisfactorily completed. The former, shown in Fig. 2, is extremely simple and is similar to that described

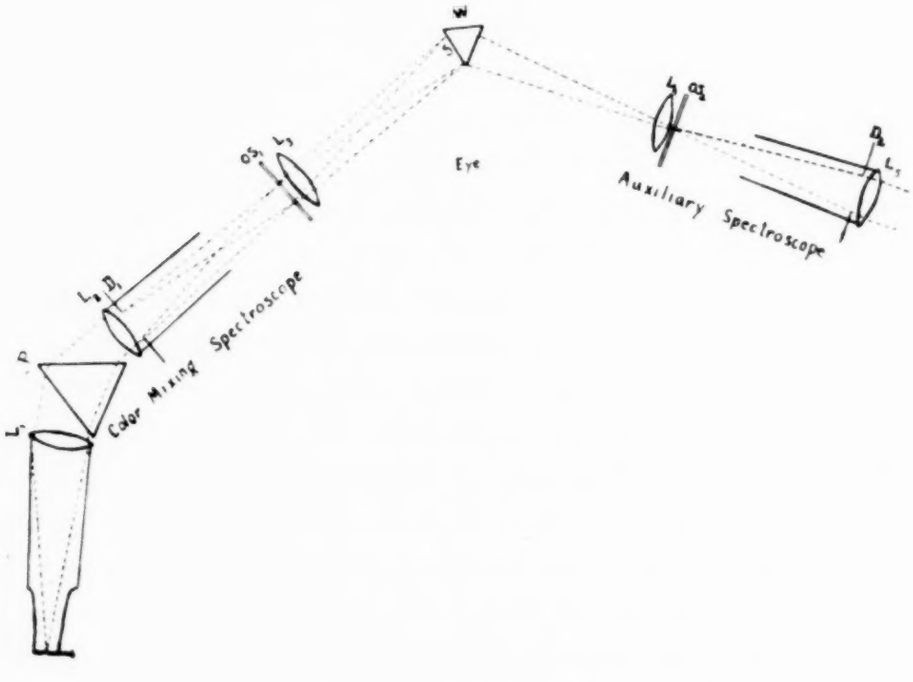

FIG. 2. Optical system

by Helmholtz and Abney. It can be used for many, if not most, of the purposes for which a color-mixer is needed. It consists of a diaphragm D_1 the opening in which serves as an object to be imaged in the mixed colored light and as a guide for definiteness of focussing in the formation of that image; a double convex lens L_3 to form the image; and a diffusing surface of a high coefficient of reflection, *e.g.*, magnesium oxide or magnesium carbonate, to receive the image. The diaphragm D_1 may be placed just back of the objective lens L_2 of the spectroscope, or even just in front of it; the focussing lens L_3 just back of the objective slit OS_1; and the screen S in the image plane of the diaphragm. When this is done an image of the diaphragm is formed in light uniformly mixed from the two, three or four slits as the case may be, the size of which will depend on the diopter value of the lens used and the distance of the diaphragm from that lens. As already indicated, the proportions of the components entering into the mixture may be regulated at will by means of the control plates, provided to vary the heights of each of the slits. Obviously these plates may be used also for the control of the intensity of the mixed beam of light, *i.e.*, the components can be mixed at any level of intensity from full to extinction. To facilitate the use of the plates for this and other purposes in the control of intensity, each plate has been provided with a scale and micrometer screw. Also, if desired, other means may be used for the control of the intensity of the mixed beam of light, *e.g.*, a sectored disc; two filters of exactly similar gradations of transmission, travelling in opposite directions across the beam of light; an iris diaphragm, with a slight modification in the optical system; the collimator slit; etc.

If it is desired to color-match or to spectrocolorimeter the mixed color obtained, a simple photometer head, such as the Ritchie wedge W, or a more complicated one, such as the Lummer-Brodhun cube supplied with an eye-piece, may be used to receive the lights to be compared; and a second or auxiliary spectroscope similar to the first, to furnish the standard color. In order that an image of the same size and shape may be obtained for the unmixed spectrum color, this

second spectroscope may be provided with an optical system, consisting of a diaphragm D_2, a slit OS_2 and a lens L_4, similar to that used for the color mixer, and with a control plate for the variation of the intensity of light. It may be supplied either with a single slit and control-plate or, if it is desired to add a variable achromatic component, the energy of which may be specified as well as the energy of the standard color, three slits may be provided, two upper slits spaced for a complementary pair of colors with control plates to vary the intensity, and a third lower slit to supply the standard color.

If it is desired to use the mixer as a colorimeter by the monochromatic, two-, three- or four-color methods, the opposite surface of the Ritchie wedge may be used to receive the unknown color. When so used, as already indicated, an achromatic component formed by the combination of complementary colors, the energy specification of which can be made, may be added when the monochromatic or two-color methods are used; and by reflecting white light into the beam from the surface of the prism, when the three- or the four-color methods are employed.

It is quite obvious that the optical system just described can not be used for focussing the light on the eye as a method of securing a color-field, even though the light emerging from the image formed by the mixing lens were collimated and focussed on the eye in accord with the usual method of so presenting the light. When this is done the image is formed within the refracting system of the eye, theoretically at the optic center, and the rays diverge and tend to separate out again before reaching the retina, presenting to the view of the observer a surface in the mixed color surrounded by fringes of the component colors. Plans are under way for utilizing slits of the type noted above in combination with the method of focusing on the eye, but they will not be discussed until they are satisfactorily completed.

While the instrument described has been devised to meet the needs of the work in our laboratory and to conform to its resources and equipment, there are some advantages of a more general purport which may be noted. (1) The mechanical

construction is simple and should fall within the capabilities of any good instrument-maker of the college type. (2) With the exception of the special slits, the apparatus can be assembled from any good laboratory equipment and dismantled at will. Excessive resources and equipment are not thus tied up in a fixed piece of apparatus which can serve only a limited purpose. (3) The optical equipment is simple. Bi-refracting prisms, Nicol's prisms, etc. are not involved. Carbon bisulphide prisms are used in our spectroscopes. They are inexpensive and give little trouble if reasonable precautions are taken to keep the room at uniform temperature. The only expensive items are the triple achromatic collimating and objective lenses of the large size needed for a spectroscope designed to give a high intensity of light. We wish to note here also that the ribbon filament tungsten lamp of recent invention is a less troublesome high intensity source of light than the Nernst filament which we have previously used. (4) In the use of a bi-refracting prism, for example, for obtaining the colors to be combined and a Nicol's prism for varying intensity, a great deal of light is wasted by the low transmission of the prisms employed. In the use of multiple slits for obtaining the colors to be combined and a variable length of slit for the control of intensity, this wastage is not involved. (5) The needs for qualitative work in color-mixing are satisfied over a wide range of possibilities. And (6) color-mixing may be made quantitative. This opens up a wide range of possibilities of investigation of this more complex of the visual responses and of its comparison with the simpler responses.

Special advantages accrue from focusing the light on the eye which may also be indicated here. (1) The method is much more conservative of light. A very wide range of intensities may be covered which is very important in some of the problems we have in mind. (2) The work may be done under light- as well as dark-adaptation without the damaging admixture of light from the room. (3) The need to use the unsatisfactory artificial pupil for the control of the amount of light entering the eye as the level of intensity is changed is

eliminated. The beam of light is focussed into an image which is smaller than the pupil and of constant size. And (4) in connection with our rotary campimeter,[1] constructed for use with the spectroscope, color-mixing can be done with any part of the retina from fovea to far periphery over a wide range of intensity of light. When using the method of focusing on the eye it is possible also to do this work with the proper control of brightness of pre-exposure and surrounding field, without which the investigation of the color-functions in the periphery of the retina is practically valueless.

[1] C. E. Ferree, Description of a rotary campimeter, *Amer. J. Psychol.*, 1912, *23*, 449–453; C. E. Ferree & Gertrude Rand, A spectroscopic apparatus for the investigation of the color sensitivity of the retina, central and peripheral. This JOURNAL, 1916, *1*, 276.

A PENDULUM-PHOTOCHRONOGRAPH [1]

BY RAYMOND DODGE

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Our pendulum photographic recorder is a combination of photochronograph and general myograph with the following characteristics: (1) It has the important advantage for psychological work of being practically noiseless; that is to say, it is noiseless until the interval to be recorded is well over when the pendulum scrapes along a piece of velvet as it is caught to prevent a return swing. (2) It is adapted to time measurements varying from .0001″ to 1″. (3) As many as fifty reaction records may be taken on a single strip of sensitized paper $2\frac{1}{2}$ inches by 7 inches in size. (4) A single count of the time-ordinates suffices for reading the entire series. If every tenth time-ordinate is emphasized, the process of reading the chronographic record is but little more exacting than reading elapsed time on a chronoscope. (5) In addition to these advantages, the pendulum recorder is economical in respect to time of operation, laboratory space, and record material.[2]

Our laboratory model was built up on a heavy pendulum which happened to be available. The pendulum was supported on steel knife-edges which were mounted on a heavy maple frame. The maximal amplitude of swing is an arc of about sixty degrees.

[1] This instrument of precision for psychological laboratories was developed at the Wesleyan Laboratory in 1915 in connection with plans for a study of human variability, which were carried out with the support of the Ernest Kempton Adams Fellowship of Columbia University. It is being described separately to facilitate the publication of a dependent study.

[2] A simple but serviceable model was constructed on the general principle of our laboratory instrument by a former assistant in the Wesleyan laboratory, Mr. H. A. Richmond. The expense of the material for this simplified model was under fifteen dollars including the cylindrical lens. The simplified instrument could be used in a semi-darkened room either on a table or on the wall. Unfortunately the war prevented him from publishing a description of his construction.

A photograph of the original pendulum was published some time ago in another connection.[3] In that study, it operated as an exposure instrument. One end of the bar which carried the knife-edges was then fitted with a screw clamp by which discs up to a meter in diameter could be mounted on the pendulum concentrically with its axis of rotation. When the pendulum was remodeled as a photographic recorder these discs were supplanted by a film carrier. This consisted of a thin strip of wood 7 in. wide and about 20 in. long, on the lower edge of which (*i.e.*, furthest from the axis of the pendulum) a metal frame was arranged to hold a pack of sensitized papers.

In front of the pendulum, that is to say, between it and the recording light, an opaque screen was interposed. Towards the pendulum and directly in front of the sensitized paper this was faced with black velvet. Behind the pendulum an opaque cloth screen was attached to the frame-work. These two light screens were connected at both edges and the top, making a partially light-tight housing. More complete screening was not necessary. In a partially darkened room such as is desirable for photographic recording I have found no significant deterioration of sensitive paper which was left in the apparatus for several days.

The front screen was pierced at the height of the record paper by a vertical rectangular opening 6 cm long by 1 cm wide. When the pendulum was at rest in its central position of equilibrium the light from the recording lamp, shining through the empty slit, would have bisected the paper with a rectangular beam of light. This rectangular beam was brought to a linear focus on the record by a cylindrical lens, 6 cm by 1 cm, which completely filled the slit. As the pendulum swung it carried the sensitized paper through this line of light. Any interruption of the recording light as the paper moved across it produced a shadow record. By the successive selection of small sections of the recording beam a series of positive records can be made on each sheet of sensitized paper

[3] An experimental study of visual fixation, *Psychol. Rev. Monog. Suppl.*, 1907, no. 35, p. 39.

with successive swings of the pendulum. Such series of positive records could be extended on each sheet to any convenient number. Fifty simple reaction records could be made without confusion. Typical positive records are repro-

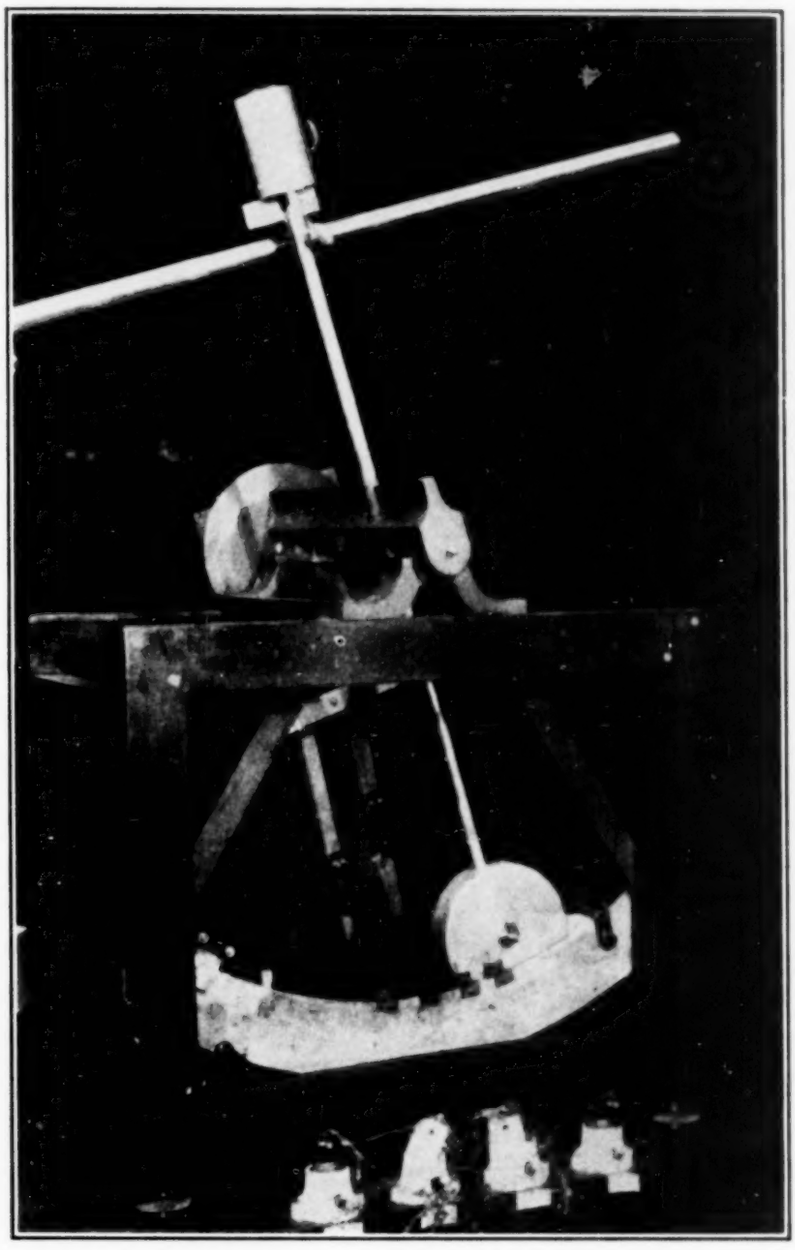


FIG. 1. Back of the photochronograph, showing contacts.

duced in Plate 1, Figs. 3 and 4. Figure 3 is a record of seven quadriceps reactions taken in a study of the knee-jerk. Fig. 3 is a series of records of 20 word-reactions. In this case the total record shows the general distribution of the series. For

each of these processes a special recording device was interposed between the arc-light illumination and the front of the cylindrical lens. The knee-jerk was recorded by means of a thin cardboard screen which was attached to the end of a small lever moving vertically in the direction of the axis of the cylindrical lens whenever the quadriceps muscles thickened. The cardboard screen was pierced by a slit which permitted a narrow beam of light to fall across the lens. This was brought to a focus on successive parts of the sensitized paper as the pendulum swung and produced a dark-line record of the reaction. It was found practicable to record six or seven patellar reflexes on each strip of sensitized paper. A typical record is reproduced in Fig. 3.

The lid-reflex was recorded by interposing an artificial eye-lash between the light and the cylindrical lens. This artificial eye-lash was cut from thin white paper and was approximately 1 mm in width and 10 mm long. Two millimeters from one end the strip of paper was bent at right angles to form an L. The short arm of this L-shaped strip was attached to the eyelid, just above the natural eye-lashes, with a drop of liquid glue. Since these were shadow records, it proved impracticable to take more than one on each strip of sensitized paper. A typical record is reproduced in Fig. 2.

The voice reactions to word stimuli were recorded in series of twenty. To make this possible, an auxiliary screen was brought in front of the cylindrical lens, where it was adjustable in a vertical track. This screen was pierced by a narrow horizontal slit which was covered by an electromagnetically controlled shutter, except at the two moments of stimulation and of reaction when the current to the electromagnets was broken respectively by the exposure device and by the voice-key. The moments of exposure appear on the record as a series of short black lines on or between the curved abscissae. These lines reappear to indicate when the words are spoken. Sample word-reaction records are reproduced in Fig. 4.

In order to permit only one exposure for each double swing of the pendulum the sensitized paper must be protected from the light on the return swing. For this purpose a small

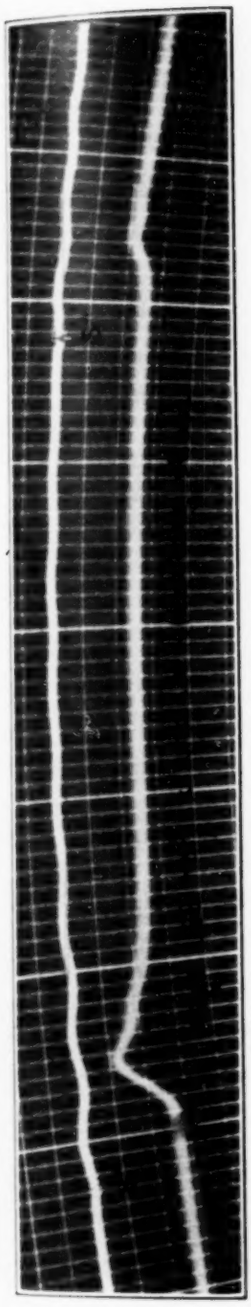


FIG. 2

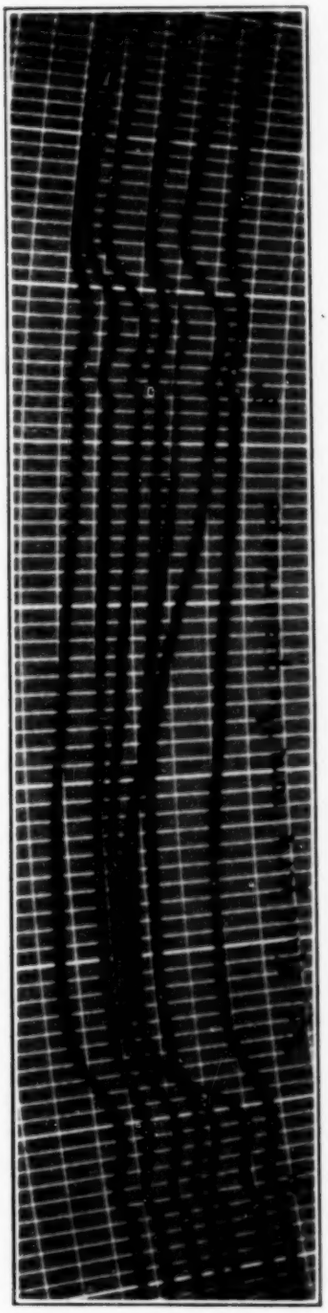


FIG. 3

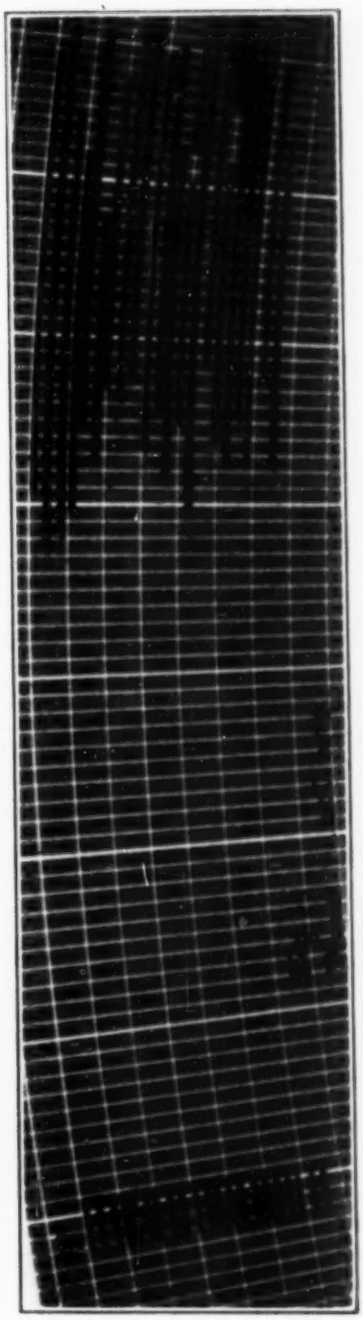


FIG. 4

PLATE I. FIGS. 2–4. Records made by photographic pendulum recorder

shutter was automatically drawn into place between the lens and paper immediately after each exposure. It was automatically drawn out of line of the recording beam of light when the pendulum was set for the next record.

A heavy brass arc is attached to the metal frame-work that carried the pendulum, at the height of the pendulum bob. On this arc are placed the rotating contact-breakers, which were in series with the stimulating instrument for the knee-jerk and lid-reflex records, as well as for the word-reactions.

In our experiments the pendulum is usually set in motion by raising a small counter-weight which is attached by a cord to a metal arm above the axis of the pendulum. This counter-weight serves to hold the pendulum ready for each new record. It is raised by hand. Whenever several records are to be taken on the same plate a practice series should be run for each new assistant until successive releases show no error which is significant for the measurements.

All records which are made by pendulum recorders rise from base-lines which lie on the circumferences of concentric circles. The radius of any one of these circles is the vertical distance of the record from the axis of rotation of the pendulum. Time-ordinates appear on the records as radii of these concentric circles. They are produced by rhythmic interruption of the recording beam of light by means of a toothed wheel which was mounted on the axis of a synchronous motor run by an electromagnetic tuning fork. Our synchronous motor rotates five times a second with a 50 d.v. fork and cuts the recording beam twenty times for each rotation producing time-ordinates which are separated by intervals of .01". Following a familiar phototechnical device, two of the teeth are broader than the others and give correspondingly broad time-lines. In this way every tenth time-ordinate is emphasized. There is a consequent saving of time and fatigue in reading elapsed time.

The curved abscissae are produced by shadows from a grid of fine silk threads on the cylindrical lens. These abscissae are approximately five millimeters apart. Since the time-

ordinates are radii of concentric circles the curvature of the base-line introduces no error in the records. With sufficiently numerous concentric circles for comparison it appears to be just as easy to determine where a curve rises from a circular base-line as it would be to determine where it rises from a straight line.

A DEVICE FOR CONTROLLING THE TIME OF EXPOSURE IN THE DODGE TACHISTOSCOPE

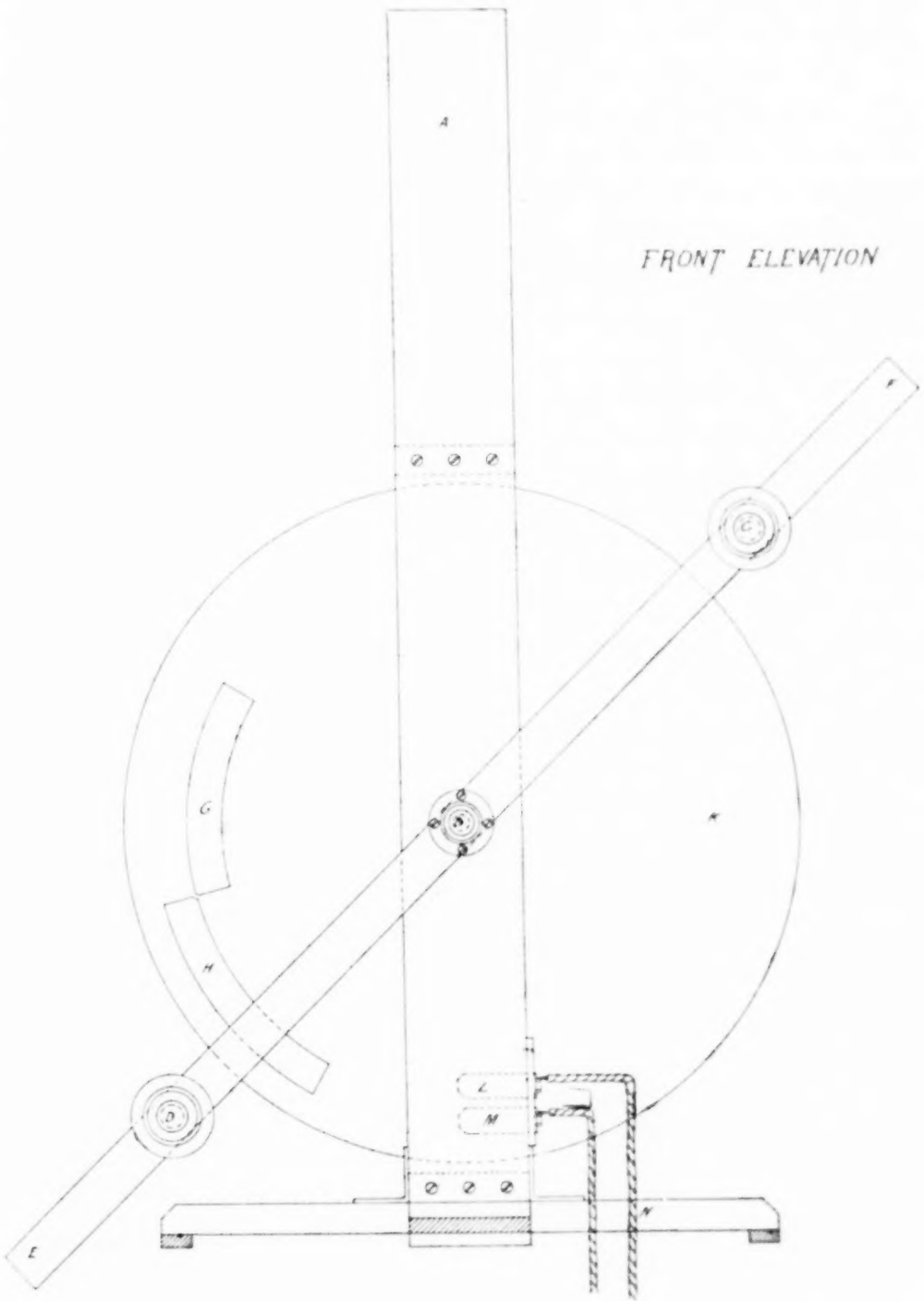
BY H. R. CROSLAND

University of Oregon

The carrying through of several projects directed at the legibility of printed characters has necessitated the supplanting of the Whipple tachistoscope with a vertical type of Dodge mirror-tachistoscope. This latter apparatus, however, lacks a device for the controlling of the time of exposure, a problem the solution of which with the Whipple tachistoscope had been effected by a gravity-propelled disc carrying a calibrated aperture through which light passes to the exposure field for a fraction of a second. Having made the change from the Whipple to the Dodge apparatus, we set about working out a device for time-control. Correspondence with Professor Dodge himself, who has had much experience with such apparatus, furnished us with several designs of shutter; one of these was tentatively selected and efforts at construction were begun. The type selected, however, presented several difficulties to the mechanician [1] who was engaged to carry out the plans, and gave promise of presenting difficulties after construction with reference to the shutter's passage between the source of light and the frosted windows of the tachistoscope. Such circumstances forced the author to attempt to construct an apparatus which, by making and breaking the light current, would obviate the objections to the shutter arrangement and would give us light exposures for fractions of a second. Consequently, he designed a rotating disc, much like Whipple's, but of 3-ply veneer wood, $\frac{1}{4}$ inch thick, to carry copper contact

[1]Mr. Frank Ackley, of the Chemistry Department of the University of Oregon, deserves credit for the fine workmanship exhibited in the apparatus. The drawings were made by Mr. Linn Forrest, of the School of Architecture. That 3-ply veneer wood could conveniently serve as our rotating-disc was suggested by Mr. T. D. Cutsforth, of the Psychology Department. Help in calibrating the time of exposure of the light itself and in controlling voltage has come from the Physics Department.

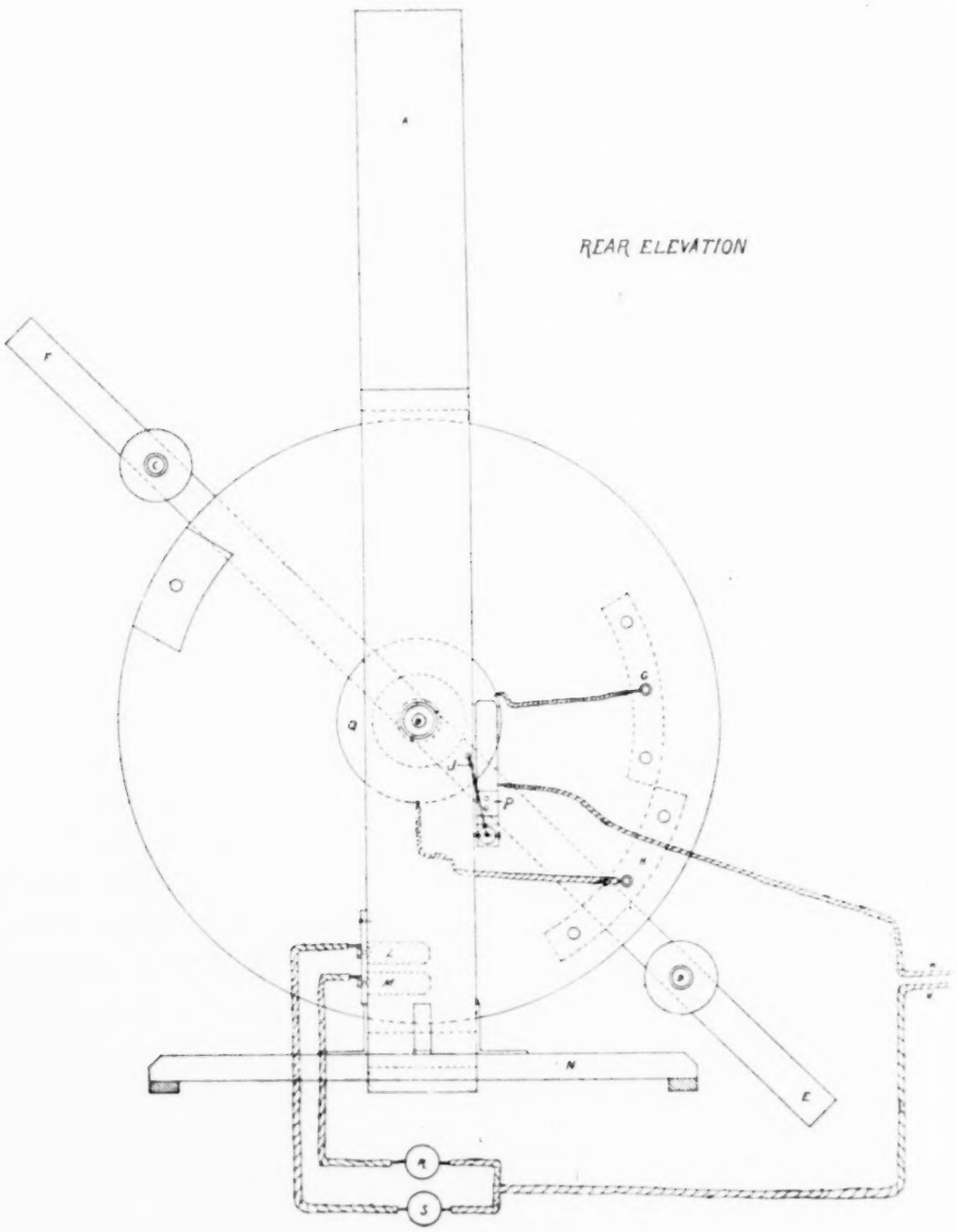
plates, so arranged that the lengths of the plates, wired through the disc to a continuous plate, would give a light through each of the two windows of the tachistoscope for exactly the sigma of time required. This disc is actuated in its rotation by weights on lever-arms, as in the Whipple apparatus; and the principle of contact-making has been borrowed



from a form of brush-contact common to several pieces of apparatus no one of which was specifically in mind when these plans were formulated.

The three plates which accompany this exposition will serve to make clear the parts of the apparatus and their arrangement.

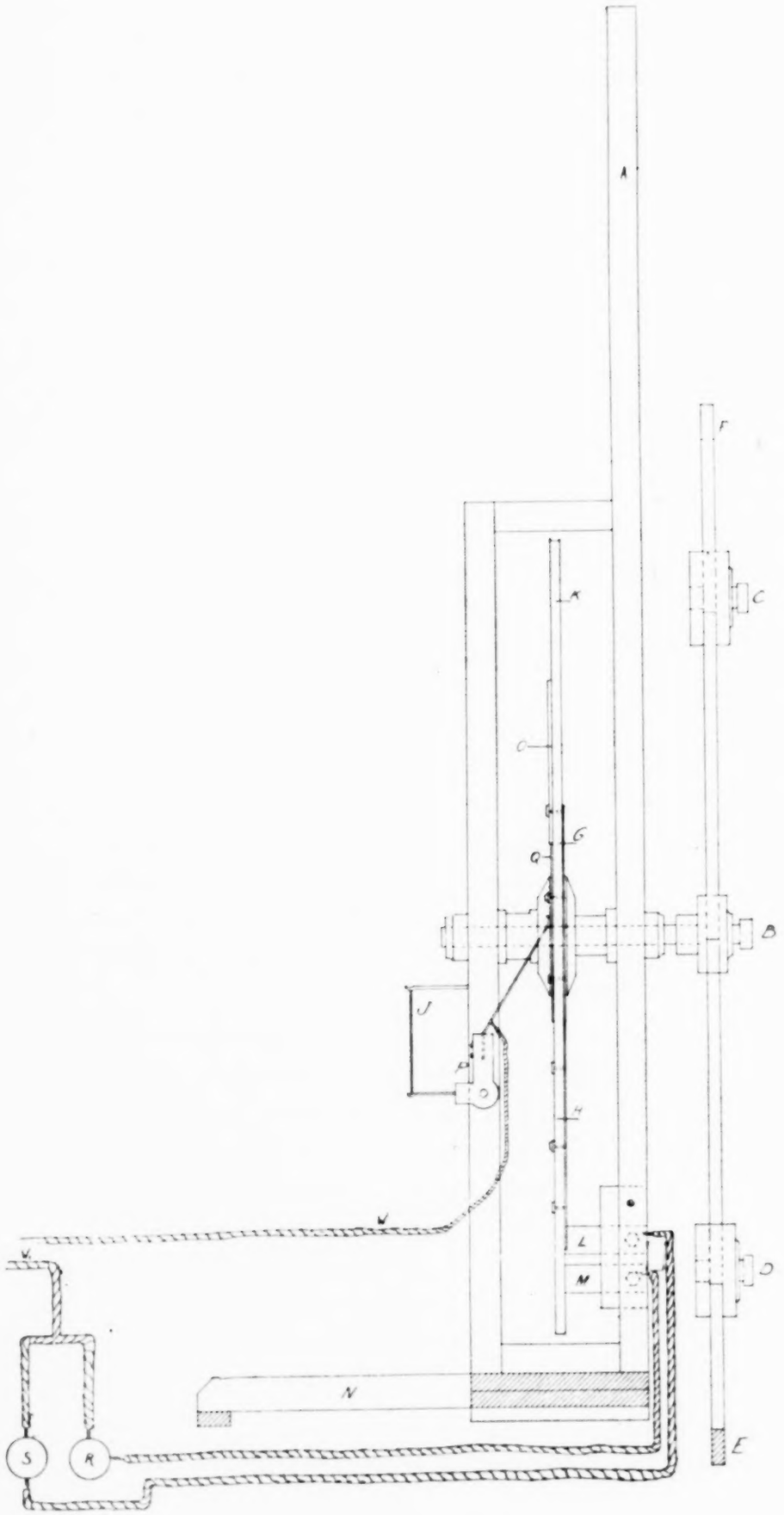
A–N represents a wooden standard which rests upon a T-shaped base which screws firmly to the top of a table, *A* being



the upright and *N* the base. At *B* is located a non-sliding but rotating screw-socket holding the meter-stick lever-arms *E*, *F* in position. Behind *B* is the axle of the disc, made of hand-milled steel as are also the bearings, giving a minimum of play or lost motion or untrue rotation of the disc. The lever-arms are held by fulcrum *B;* and *C* and *D* are adjustable weights with center screws holding them tightly in position. *K* is the rotating wooden disc. *H* and *G* are the copper contact-plates, which, in the fall of the lever and the rotation of the disc, engage the metal spring contacts *L* and *M*. The latter, *L* and *M*, are wired in circuit with one of the wires (W_1) from a wall-socket furnishing 125-v a.c. energy, whereas *H* and *G* are wired, through the wooden disc, with metal-plate *Q* (see rear view, below), which is a continuous band always in contact with the spring *P*. The latter, *P*, is supplied with the other wire (*W*) from the wall-circuit. *R* and *S* represent the two 25-watt tungsten lamps which are placed in the two separated compartments leading to the two frosted windows in the rear of the Dodge tachistoscope. *J* represents a rubber-band which gives leverage to *P* against the contact-plate.

The rear and side plates, shown herewith, present the complete circuits of wiring, which are so arranged, with their contact-plates and spring-contacts, that the light in each compartment goes on, with a part-rotation of the disc, for 100 sigma, and just as it goes off, the second light, in the other compartment, goes on for 100 sigma.

Two possible sources of error, from this arrangement, might arise from two sets of inertias, one for the metal contacts and the other for the light-bulbs themselves since it is well-known that the initial lag of a bulb is greater than its terminal or final lag. Two procedures have been followed to eliminate these sources of error. One of these consists in using nitrogen-filled bulbs, and the other consists in calibrating the exposure-time of the light itself directly at the eye-piece of the tachistoscope by filming the shadow of a hair supported by one tyne of a 100 d.v. tuning fork. Adjustments and corrections are experimentally instituted with respect to the lengths of the copper-plates, *G* and *H*, as a consequence of the measurement


SIDE ELEVATION
A
F
C
K
G
B
J
H
L
M
O
N
E
S
R

of the exposure of the light; the plates, amply long to begin with, are shortened with tape at their non-proximal ends and the speed of the disc is varied also by shifting the weights *C* and *D*.

Another source of error which might prevent the accurate control of the light inertias and also the brightness of the light would be the variations in the voltage of what is supposed to be a 125-v a.c. circuit. We have planned to circumvent this possible source of error by placing a rheostat and a voltmeter in circuit with our lights, cutting down the voltage to 110, and then by keeping the voltage at 110 by the rheostat for each experimentation. We reckon that the frosted windows, through which the light must enter the tachistoscope, and the system of reflecting mirrors inside it, with the interior painting, act somewhat as filters and hence make negligible more minute variations of brightness other than those which would arise from daily variations in voltage.

A final source of error in the use of our apparatus might conceivably arise from the untrue rotation of the disc; *i.e.*, from lateral vibrations as the disc turns on its axle, resulting in the failure of the contact-makers to function here or there on the metal plates or in a non-synchronizing of the break-make between the two plates *G* and *H*. We believe that three features of the apparatus prevent errors of this sort: (1) the pressure from opposite sides of the disc is kept constant and in force by springs which hold the contact-makers against the metal-plates. (2) A ballast, or fly-weight, is situated at *O*, to counteract the pressure of the contacts *L* and *M*. And (3) the superfluous weight on the short lever-arm of *E–F* functions somewhat as a ballast. The fine hand-workmanship of the axle and bearings reduces to a minimum the lost motion.

To summarize: we believe that the vertical type of Dodge mirror-tachistoscope has virtues not possessed by the Whipple tachistoscope; nothing moves before the eyes, light is more equally distributed over the exposure-field, and a non-moving pre-fixation field (equal in brightness to the main field) is afforded. Our timing apparatus has these virtues; time can be controlled as accurately as, if not more accurately than,

with the Whipple timing-disc; it serves, with the Dodge apparatus, to present no moving object in the fixation-field; it serves to equate in both brightness and length of exposure the pre-fixation field with the main field; and, lastly, our timing device rests on one table (if necessary in an adjoining room) and the tachistoscope on another, so that there is no jarring of the apparatus during exposure.